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STUDIES ON REPRODUCTION IN CATTLE

Pt. II. THE INFLUENCE OF ENVIRONMENTAL FACTORS ON REPRODUCTION

JAMES ANDERSON

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WITHIN recent years numerous investigations have been made on the relationship of such environmental factors as rainfall, temperature, light, and food, to reproduction, and there is now evidence to show that some of these factors do influence reproduction to some extent.

Effect of rainfall.—Baker and Ransom [1] collected field-mice (*Microtis agrestis*) from different areas over a period of two years, and in an investigation of their breeding-habits failed to find any correlation between breeding and rainfall.

Effects of temperature and light.—Under natural conditions fecundity in both sexes of the field-mouse starts in the coldest time of the year in Britain, namely February–March, and stops when the temperature is still high. Thus temperature would not seem to play an important part in influencing reproduction in this species. On the other hand, under experimental conditions, it was found that a low temperature (about 5° C.) interfered with reproduction in female mice, but the way in which it works is not known [2]. In the rat it has been shown that exposure to cold lengthens the oestrous cycle, and it is thought that this change is brought about through the lowered general metabolic level, since both body-temperature and general activity are reduced [3]. Parkes and Brambell [4] have found that mice kept at 0° C. experience regular oestrous cycles.

Rowan [5] found that artificial illumination in midwinter induced sexual activity in the Junco. Bissonnette [6] found that complete spermatogenesis and maximum testis-size could be induced in 4–6 weeks at any time from December to April in the starling by giving light exposures of 6–7 hours per night, and, conversely, that birds kept in winter light in April, May, and June, when normally in nature the testis attains full reproductive function, did not show any reproductive activity. He showed also that light and not exercise is the responsible factor, for the testis of birds on forced-exercise periods without added light actually became smaller and less active in spermatogenesis. It was, moreover, shown that the degree of stimulation depended on the intensity of the illumination and on the wave-length of the light used. Red light was highly stimulating, but green light of an equal intensity was slightly inhibitory to the activity of both testis and ovary. In the female ferret, on the other hand, Marshall and Bowden [7] found that none of the wave-lengths employed by them caused retardation of the recurrence of oestrus. The recurrence of oestrus in the ferret was greatly accelerated by light of various wave-lengths. Ultra-violet light was the most effective. Green, red, and yellow were also effective in this order.

Infra-red had a slight effect and violet a very small effect, if any at all. The effective radiation extended from red (λ6500) to the near ultra-violet (λ3650), and over this region of the spectrum intensity was more important than wave-length. There was a fairly sharp threshold on the long wave-length end of the spectrum, in that λ7500 was scarcely effective, although its intensity was high, whilst λ6500 gave a marked response.

Bissonnette [6] has found that an increase in the duration and intensity of daily exposures to light induces oestrus in the female ferret whereas reduction in the intensity and period of exposure brings about an anoestrous condition. Hill and Parkes [8] have shown that the effect of additional illumination in inducing oestrus in the ferret in winter depends on the presence of the pituitary body. These workers also found that almost total exclusion of light does not seriously affect the onset of the breeding season in this animal, which is in accordance with the fact that, histologically, breeding changes can be seen in December, long before an increase in the amount of daylight occurs [9]. Hill and Parkes therefore conclude that, whilst additional light will induce oestrus in the anoestrous ferret, the onset of the breeding season in the spring is not dependent on the increasing length of daylight. They prefer to regard anoestrus as merely one phase of the oestrous cycle that is known to depend on some inherent rhythm of the anterior pituitary body. Marshall's criticism of this is that, if there were no external factor involved in the recurrence of oestrus and the problem were merely that of the dioestrous cycle in the mouse, there is no apparent reason why the periodicity of sexual activity in the ferret should so generally conform to that of the seasons. He also points out that in comparing the dates of vulval swelling given by Hill and Parkes with those observed by Hammond and Marshall [10], there was on the average a definite lag in the time of the onset of oestrus. Bissonnette [6] also noted that there was a delay in the onset of oestrus in two hooded ferrets. It would therefore seem that there is an inherent rhythm in the sexual life of the ferret, but that light is an auxiliary factor. On the other hand, Marshall has reported the case of a blind ferret which has never experienced oestrus; and it has also been found that in blinded toads (*Xenopus*) the ovary was under-developed [11].

In observations on the breeding of the field-mouse, Baker and Ransom [1] noted a remarkable general correlation between the hours of sunshine and reproduction in this species. In general, breeding occurred only in those months in which there was more than 100 hours of sunshine. This finding was supported by an experiment in which a reduction of the daily period of exposure to light from 15 to 9 hours almost prevented reproduction in the field-mouse [12].

Nutritional Factors and the Oestrous Cycle in Animals

Under-nutrition has been associated with sterility in many animals. It has been noted that the oestrous cycle in rats is not affected by mild nutritional deficiency, but it is lengthened when the diet is very poor; the cornified-cell stage is said not to be affected [13]. In the guinea-pig,

Papanicolaou and Stockard [14], and in the rat, Long and Evans [15] have found that under-feeding increases the length of the inter-ovulation period. Macomber [16] has also noted that a reduction of 30 per cent. in the total amount of food greatly prolonged the interval between periods of oestrus in the rat. Loeb [17] found that rats underfed on a normal ration failed to ovulate, and that follicles underwent degenerative changes.

Over-feeding likewise interferes with breeding efficiency. It is often difficult to get fat animals to breed, and Hammond has shown that the duration of oestrus and the length of the cycle are shortened in animals in fat condition. A considerable amount of lipochrome has been found in the ovaries of fat heifers [18]; and Hammond suggests that the decreased length of oestrus in fat animals may be caused by a blockage of the ovarian cells with lipoids.

Evans and Bishop [19] have found that fat-free diets interfered with ovulation, but no such interference was attributed to carbohydrate-free diets.

Guilbert and Goss [20] noted that in rats the oestrous cycle was normal with a protein-intake of 7·5–8 per cent. Lowering the protein-intake to 3·0–3·5 per cent. resulted in cessation of oestrus or in long, irregular cycles. It is not known to what extent an inadequate protein-intake, permitting oestrus (but not fertility), in some animals interferes with ovarian changes, for numerous *corpora lutea* that may have been newly formed, or may have been retained from the last oestrus, were found in the ovaries of such animals 70 days after the last occurrence of oestrus. The importance of the quality of the protein has been shown by Courrier and Raynaud [21], who found that the sexual cycle did not occur on a diet deficient in lysine.

Guilbert and Hart [22] found that a low phosphorus-intake caused cessation of the oestrous cycle in rats; in some cases irregular cycles occurred and the cycles were lengthened. A change to a diet adequate in phosphorus caused oestrus to start within a few days. The importance of the calcium-phosphorus ratio, as well as the actual amount of phosphorus in the diet, is shown by the fact that oestrus ceased on a diet low in phosphorus and high in calcium, but began again on transferring the animals to a diet containing an amount of phosphorus similar to that in the previous diet but with a low calcium-content. Lack of phosphorus in the diet is said to cause cessation of oestrus in cattle [23, 24]. In South Africa phosphorus-deficiency is associated with sterility in cattle [25, 26] and in Norway, Tuff [27] has noted that a naturally occurring deficiency of calcium and phosphorus in the food causes failure to ovulate. Contrary to these findings, Boyd [28] states that experiments still in progress (no details given) on the effect of phosphorus on reproduction show that there is no interference with the rhythm of the oestrous cycle in cattle.

The inability of rats to reproduce successfully when fed on a ration of milk alone is generally thought to be due to milk being low in certain substances necessary for reproduction. Ovulation was delayed and irregular in rats on a milk diet supplemented by copper and iron, but

the addition of manganese and iodine improved the ovulatory rhythm [29]. Skinner, Van Donk, and Steenbock [30] found that even on a milk-copper-iron diet supplemented with manganese, rats showed irregular and infrequent cycles. On the addition of sucrose to this diet normal oestrous cycles (4·3 days) occurred, and on the milk-copper-iron diet with sucrose, but without manganese, the oestrous cycles were regular but longer in duration (5·4 days). The deficiency of this diet with regard to oestrus therefore seems to be one of energy, although the maximum response was not elicited without the manganese. On the other hand Orent and McCollum [31] failed to find any interference with the periodicity of oestrus on a manganese-free basal diet, and on a milk-copper-iron diet. The author has noted that injection of oestrin in the form of urine from a pregnant cow into mice in which oestrus has ceased entirely, due to an exclusive milk diet, will induce oestrus again [unpublished results]. The failure of such mice to exhibit oestrus is therefore apparently due to non-production of oestrin.

There is almost complete cessation of oestrus in rats when the sodium-fluoride intake exceeds the threshold value of 25 mg. F per kg. body-weight [32]. Rats fattened on brain and cholesterol had longer dioestrous periods, but lecithin increased the duration of oestrus [33].

Vitamin-B deficiency is associated with atrophic changes in the male and female gonads. According to Evans and Bishop [19], this deficiency results in cessation of oestrus in rats. Marrian and Parkes [34] have found that the administration of anterior pituitary substance induced oestrus in the anoestrous condition caused in the rat by inanition or vitamin-B deficiency, and it has been found that oestrin has a similar effect in vitamin-B deficiency [35, 36].

Verzar [37] has shown that the intra-peritoneal injection of vitamin E into immature female rats caused hypertrophy of the uterus, but no such effect was observed in ovariectomized animals. Male rats reared on a diet free from vitamin E had a silky infantile coat similar to that of castrated rats; the addition of vitamin E to the diet, or the injection of anterior pituitary hormone into rats on that diet, caused the development of the bristly coat characteristic of the normal male. It is therefore suggested that vitamin E is necessary for the synthesis of anterior pituitary hormone [38]. Vogt-Moller and Bay [39, 40] have used extracts of wheat-germ oil against sterility in the cow with considerable success.

In view of the relationship known to exist between the anterior pituitary and the gonads, several workers have investigated the gonad-stimulating properties of the anterior pituitary of rats on diets deficient in various factors. Marrian and Parkes [34] transplanted the pituitaries from rats lacking vitamin B into immature anoestrous rats, and obtained a response similar to that with pituitaries of normal rats. Similarly, fairly high doses of fluorine do not seem to affect the gonad-stimulating potency of the anterior pituitary in rats [32]. On the other hand, Mason and Wolfe [41] obtained a 43 per cent. greater effect with the pituitaries of rats on a diet deficient in vitamin A than with controls on normal diets.

Influence of Climatic and Nutritional Factors on the Periodicity and Duration of Oestrus in the Cow

It was thought that if environmental factors affected in any way the periodicity and duration of oestrus, a correlation between one or more of these factors and the periodicity and duration of oestrus might be evident. Accordingly, meteorological data were recorded and analyses of the pasture on which the animals grazed were made. The meteorological data are summarized in Table 1. The rainfall data are available for the

TABLE 1. *Meteorological Data*

	1933											1934	
Months	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Jan.*	*Feb.*
Rainfall (inches)	3·08	3·18	7·80	9·44	5·52	4·97	6·96	5·75	4·41	3·21	3·12	0·09	1·12
Temperature (°F.):													
maximum	..	..	..	..	..	..	75·8	78·4	78·1	79·4	83·4	90·6	90·6
minimum	..	..	..	..	..	..	56·2	56·2	58·9	68·6	58·9	57·0	61·9

whole of the experimental period, but temperature records only for the months August–February. Analyses of pasture are available for the period July–February; they are given also for the months of March and May, to show the full seasonal variation that takes place. There are no particulars for April, as the grass sample arrived in a mouldy condition and could not be analysed.

Climatic Factors

Rainfall.—It is unlikely that rainfall *per se* influences sexual function, but it might act indirectly through its effect on pasture. If this were so there would probably be a latent period before any effect would be obvious. May, with fully 9 inches of rain, was the wettest month of the year, and no increase in the duration of oestrus occurred until July, two months later, which would seem to be a long interval if rain really did exert any indirect influence. Also, there was actually a decrease in the month immediately following that of heavy rain. Moreover, the monthly rainfall decreases steadily from August to January, and the periodicity and duration of oestrus over the same period shows considerable variation. It may therefore be concluded that rainfall was not responsible for the variation noted in the periodicity and duration of oestrus.

Temperature.—In general, it can be said that climatic conditions in the tropics consist of a range from wet to dry weather, as opposed to the range from hot to cold weather in temperate climates. The stock-farm where the observations were carried out was not exposed to extreme temperatures (Table 1). Unfortunately records are available for only 7 months. They suffice, however, to show that the range of both maximum temperatures (from 75·8° in August to 90·6° in February) and minimum temperatures (56·2° in August to 61·9° in February) over the period are comparatively slight. In the wetter period of the year the temperatures would be somewhat lower. All workers are not agreed that temperature does affect reproduction, but it has been shown experimentally that only very low temperatures affect reproduction in the

mouse. The temperatures to which the experimental cattle were exposed were not extreme. Moreover, although the temperature increased steadily from August to February, both the periodicity and duration of oestrus over this period showed considerable variation. It is therefore

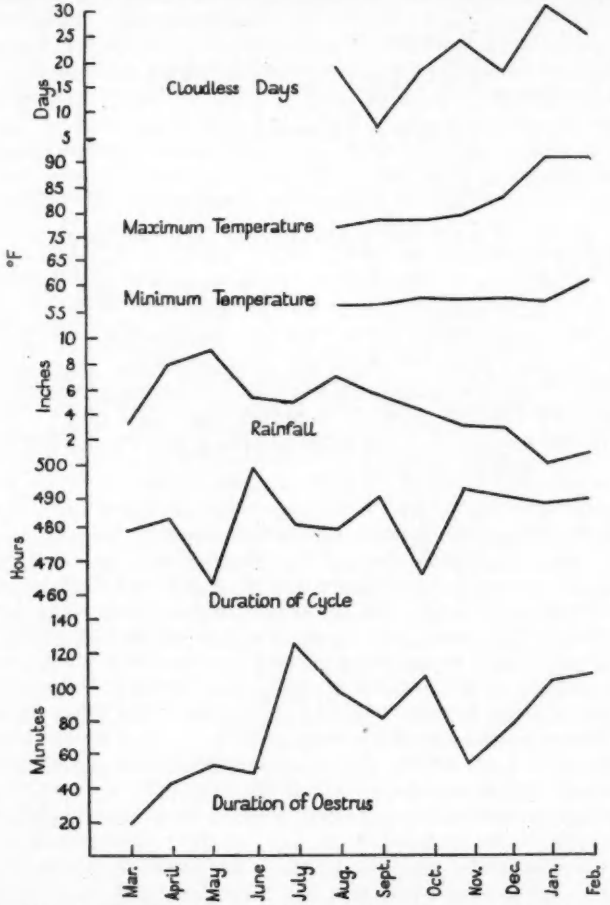

FIG. 1. Relationship between periodicity and duration of oestrus and rainfall, temperature, and cloudless days

concluded that in the present experiments temperature was not an important factor determining variation in the periodicity and duration of oestrus in cattle.

Light.—Circumstances unfortunately prevented the making of sunshine records, but a rough estimate of this factor was obtained from daily observations on the state of the weather, including the amount of cloud, and to some extent the data for rainfall and temperature (Fig. 1).

As the farm is situated almost on the equator, the length of the day varies little from season to season. Variation in the amount of sunshine must, therefore, be attributed to climatic conditions, and it may be assumed that, in general, there is less sunshine during the rainy season than in the dry season. An estimate of the state of the weather was made daily at 6 p.m., and the weather for the preceding 12 hours was also noted. For this purpose weather was regarded as: (*a*) 'cloudy', denoting a considerable amount of cloud, (*b*) 'variable sky', denoting a small amount of broken cloud, and (*c*) 'clear', when cloud was absent or at a minimum. The number of days per month with cloudy and clear weather was thus obtained (for this purpose 'variable sky' was regarded as 'clear' weather). It is admitted that this method is far from ideal, and can only give a very rough estimate of the amount of sunshine but, in the absence of more accurate data, it must for the present suffice. It will be seen from Fig. 1 that on the whole there is some similarity between the amount of sunshine, as represented by the number of days per month without cloud, and the variation in the duration of oestrus. In view of what is known of the effect of light upon reproductive functions, and bearing in mind the limitations of this method, it is apparent that the influence of light on sexual function in the cow is worthy of further investigation.

Food.—Analyses of the pasture, which formed the sole food of the animals during the experiment, is given in Table 2. It is evident that the pasture is of poor nutritive value. The contents of phosphorus, ash, chlorine, and protein, are particularly low. It is probable that the sodium-content is also low. The relationship between rainfall and pasture constituents is shown in Fig. 2.

The effect of rainfall is, on the whole, clearly reflected in the pasture constituents, an increase in the monthly rainfall being associated, in general, with an increase in the percentage of most of the constituents, and vice versa, with the exception of the month of October when, with a decrease in rainfall, an increase in the crude protein, silica-free ash, CaO and P_2O_5 occurs. The protein and silica-free ash follow each other closely, but the protein-content of the pasture increases more promptly than does the silica-free ash in response to the increased rainfall in February. Actually the P_2O_5-content parallels the protein-content much more closely than does the silica-free ash, though the variation in the P_2O_5-content is comparatively slight. Variation in the chlorine-content is likewise slight; it rises steadily till December and then falls till March, the highest value occurring in May. The CaO-content also rises till the month of October; it falls slightly in November, rises in January, falls in February, and rises again in March.

There does not appear to be any relationship between seasonal variation in the pasture constituents and variation in the periodicity and duration of oestrus. A decrease in the duration of oestrus in August–September and in October–November is accompanied by a decrease in the crude protein, P_2O_5, and silica-free ash, but while these constituents continue to fall from November–January, the duration of oestrus increases. An increase in the duration of oestrus in September–October and in January–February is associated with an increase in the crude

protein and P_2O_5 over the same period, but an increase in these constituents is accompanied by a decrease in the duration of oestrus in July–August. A decrease in the length of the cycle in November–January

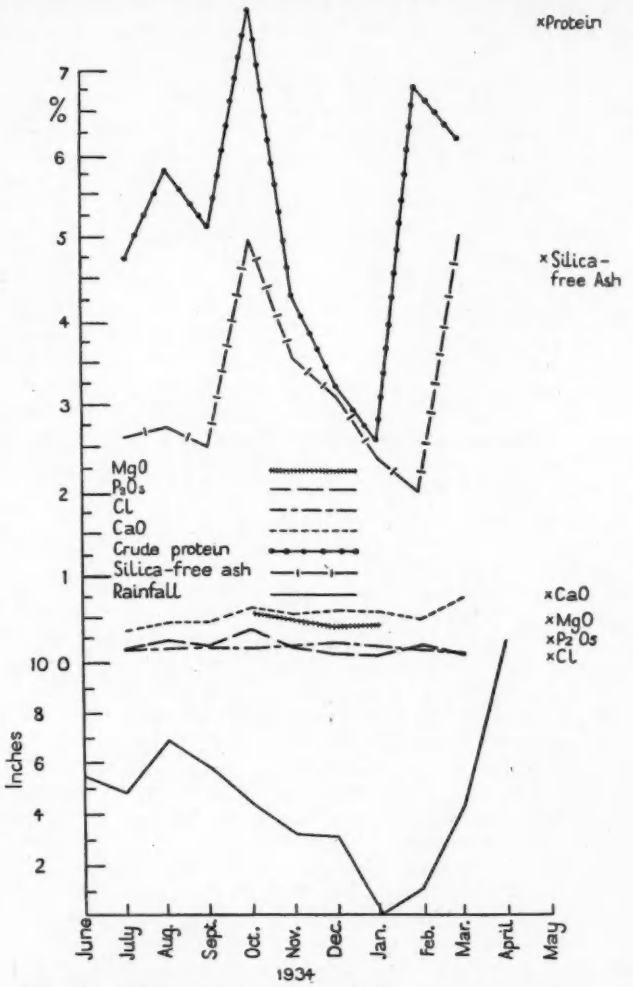

FIG. 2. Relationship between rainfall and pasture constituents

is associated with a decrease in the crude protein, silica-free ash, and P_2O_5, but an increase in the former in August to September is accompanied by a decrease in the crude protein, silica-free ash, and P_2O_5. The variation in the contents of chlorine and calcium does not correspond with variation in the periodicity or duration of oestrus. Such variation

as there is in these substances is slight, and there is no evidence that they are of great importance to reproductive functions.

Since in the method used for sampling the grass a certain amount of old grass was probably included, it is doubtful if the analyses fully represent the seasonal changes in the pasture constituents. Moreover, although no relationship is evident between the pasture constituents and the periodicity and duration of oestrus, it must be remembered that the percentages of pasture constituents shown in Table 2 do not necessarily

TABLE 2. *Analyses of Pasture Herbage*

Date of cutting	*Crude protein*	*Ether extract*	*Crude fibre*	*N-free extract*	*Silica-free ash*	*CaO*	P_2O_5	*Cl*	*MgO*
1933									
July 28 .	4·75	1·70	34·06	50·03	2·67	0·39	0·17	0·15	..
August 31 .	5·84	1·28	33·94	48·99	2·78	0·49	0·27	0·16	..
September 30	5·15	1·82	32·60	50·83	2·54	0·50	0·21	0·17	..
October 31 .	7·78	1·36	29·77	51·72	5·02	0·66	0·40	0·17	0·52
November 30	4·36	1·46	31·97	52·83	3·60	0·60	0·19	0·20	0·52
1934									
January 7 .	3·29	1·40	32·90	52·40	3·15	0·63	0·11	0·21	0·44
January 31 .	2·60	1·46	31·07	55·22	2·40	0·61	0·10	0·13	0·46
February 28 .	6·80	1·25	33·08	48·25	2·00	0·52	0·19	0·12	..
March 31 .	6·20	1·74	32·50	47·60	5·09	0·79	0·13	0·13	..
April 30 .	..	..	..	..	..	..	..	..	..
May 31 .	7·57	1·77	32·77	48·66	4·76	0·53	0·37	0·27	0·55

indicate the amounts of them consumed by the animals. No check was made on the food-consumption, and it is therefore possible that more pasture was eaten at certain times of the year than at others. It is therefore concluded that this method of correlating seasonal variation in the periodicity and duration of oestrus with seasonal variation in the pasture constituents is not one that will lead to useful results.

On the other hand, in view of what is known of the effect of shortage of protein and P_2O_5 in the diet of animals on the oestrous cycle, it is possible that the relatively small amounts of protein and phosphorus in the pasture are related to the brief duration of oestrus in the experimental animals.

Discussion

It has been shown that Zebu cattle exhibit a very short oestrous period compared with British cattle; but as the animals were living under conditions totally different from those of cattle in Britain, and on a diet poor in protein and phosphorus, the question of the relative effect of breed and nutrition on the oestrous cycle must for the present remain open.

It does, however, seem to be significant that the duration of oestrus is long at that time of the year in Kenya when there is most sunshine, namely, the dry season. The fact that the oestrous period is also long in July and October may or may not be related to the amount of sunshine. The possible significance of the relationship between the duration of oestrus and sunshine is enhanced by the facts that, (*a*) in Britain oestrus is longer in cattle during the summer months than in the winter months, and (*b*) light has a stimulating effect on reproductive function

in birds, mice, and ferrets. If light as a stimulus to reproductive function is to be regarded as a factor of universal importance, it is generally considered probable that it is the change in the light ration and not the actual amount which is the decisive factor, for most breeds of sheep, for example, commence their mating season when the hours of daylight are decreasing in the autumn, and mating stops with increasing daylight in the early spring.

Variation in the duration of oestrus can probably be related directly to variation in the production of oestrone, the hormone responsible for the oestrous phenomena in animals, and this in turn to variation in the gonadotropic activity of the anterior pituitary. It has been shown that hypophysectomy in the ferret prevents the response to light treatment which is obtained in the normal animal [8]. It is therefore possible that light is capable of stimulating the anterior pituitary in cattle, possibly through the eye.

Summary

1. Present knowledge on possible relationships between rainfall, temperature, light, food, and reproduction is reviewed.

2. The possible influence of climatic and nutritional factors on the periodicity and duration of oestrus in the cow was investigated. No correlation was found for rainfall or temperature, but some indications were found of a possible correlation between sunshine and variation in the duration of oestrus.

3. Analyses of the pasture (which formed the sole food of the experimental animals), cut at monthly intervals, were made for the period July 1933 to May 1934. No relationship was found between seasonal changes in pasture constituents and the periodicity and duration of oestrus. This line of investigation is unlikely to lead to useful results.

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THE ROOT-SYSTEM OF THE SUGAR-CANE

II. SOME TYPICAL ROOT-SYSTEMS

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WITH PLATE 13

IN the first paper of this series (1935, 3, 351) a description was given of one typical sugar-cane root-system and of the various classes of roots composing it. Although these classes of roots are represented in most sugar-cane varieties, their relative proportions vary greatly, giving rise to considerable differences in the mature root-systems. The root-systems of most of the economic varieties in Mauritius have been investigated in considerable detail, and it is proposed to describe here the most important varietal types.

The First-nobilized Glagah Type

First-nobilized Glagah canes are of no direct economic value, being the first generation from the cross of the wild Java forms of *Saccharum spontaneum* with the noble cane *Saccharum officinarum*, but they are of great value for breeding purposes. Attempts are, however, being made in Mauritius to produce third- and fourth-nobilized Glagah canes for commercial cultivation. Since the nature of the root-system of the parent types used for breeding will presumably have a marked effect on the nature of the root-system of the seedlings produced, the root-system of the parent type was studied in detail.

The surface-soil of the field where this root-system was examined was only 6 in. deep, the soil below consisting of a friable, reddish brown clay. The root-system in the first 6 in.-layer of soil is very extensive, spreading uniformly in all directions. Roots in this layer generally originated at a depth of more than 6 in. at the stool, but came nearer to the surface as they passed away from the stool, their final terminations being only 3–4 in., or even less, below the surface of the soil. Towards their terminations, the roots branched profusely, the branch-systems generally consisting of very thin and delicate rootlets. Roots 10 ft. long were found in this layer, and the number and length of roots appeared to be correlated with the vigour of the aerial portion of the stool. The roots in the surface-layer were cylindrical and rather thin, being also hard, wiry, and brownish black. They showed no compression in passing through the soil, but older roots were often ribbed, as in the shoots of some switch plants. This was shown to be due to the collapse of cortical cells at some points, leading to the depressions in the hypodermal layers. The superficial absorbing roots were confined to the first 6 in. or so of soil, the roots in the soil immediately below being buttress-roots. These buttress-roots were deep yellow to orange at the time of examination, indicating a comparatively recent origin. They did not branch to any great extent, and showed marked distortions. Most of the buttress-roots passed outwards

and downwards from the stool, generally terminating at a depth of 3–4 ft. Some passed more or less vertically downwards. In the deeper layers the roots did not pass outwards to any marked degree, but generally passed more or less vertically downwards. These deep roots, like those of the superficial system, are cylindrical, and in this variety associate to form well-defined rope-systems. The rope-systems passed down to depths of 7–9 ft. under the particular conditions of growth.

The root-system of this type of sugar-cane is thus in the main a very satisfactory one in regard to number and distribution of roots in the various soil layers. The reconstructed root-system of a comparatively small stool of a first-nobilized Glagah seedling is shown in Fig. 1, Plate 13. Many of the roots were, however, followed to much greater depths than 6 ft., which is the depth of the frame in this figure.

The POJ. 2878 × Uba Marot Seedling Type

One of the most striking types of seedling produced by the Sugar-cane Research Station is that obtained by crossing the Java cane POJ. 2878 with the Mauritius cane, Uba Marot. POJ. 2878 contains one-eighth of the wild blood of *Saccharum spontaneum*. The origin of Uba Marot is unknown, but it is certainly different from Uba, and almost certainly contains wild blood, its chromosome number being 112 or 113, most probably 113 (Bremer, 1934). The progeny of this cross have remarkable vigour, particularly in the early stages of growth. Several such seedlings have been produced to date, and some of them have satisfactorily survived field-trials for yields of cane and sugar per acre. One stool was reconstructed in a specially made frame, and a few other stools were examined in less detail. The stools examined were virgin, or plant-stools of 18 months, and bore on the average 35 canes. The root-system was one of the most extensive of all the varieties that have been examined. The surface-spread of the root-system, though appreciable, has been excelled by certain other varieties. Branching of the surface-roots was not prolific, but the number of roots in the surface-soil was very high. The typical superficial roots were not in this variety confined to the first foot or so of soil, as is generally the case. Roots in the second foot were nearly as numerous as those in the first foot. Down to a depth of 2–3 ft. the roots passed outwards more or less horizontally from the stool, contrasting markedly with the noble canes, in which roots passing outwards horizontally are seldom found below a depth of 1 ft. In addition, the noble canes seldom have many roots at depths of 4–5 ft., but this system showed very active root-development at this depth, and rope-systems passed down to far greater depths. Buttress-root development had been very vigorous, the buttress-roots being somewhat thinner and darker than in most noble canes. Below 4–5 ft., most of the roots were associated as rope-systems passing down vertically. Several rope-systems were followed to a depth of 15 ft., and at this depth there was a considerable number still descending. The number and extent of the roots from the surface-soil down to these depths were very great.

Less detailed examination of other seedlings of this cross showed that they all had very satisfactory root-systems. It is probable that selected

seedlings of this type will play an important part, particularly on lands infested with *Phytalus Smithi*, Arrow, a white-grub pest in Mauritius. The root-system in the first 6 ft. of soil is shown in Fig. 2, Plate 13.

The Uba Type

Among the Uba type are included the ordinary Uba cane together with various seedlings of Uba that have inherited the general characteristics of the Uba type of root-system.

The root-system of the ordinary Uba is the most extensive of all the root-systems examined, not excepting that of the POJ. 2878 × Uba Marot seedlings.

The Uba type of root-system was too extensive to be profitably investigated by the 'block' method, and more information was required than could be obtained from the direct-examination method. All these root-systems were therefore investigated by the progressive-section method (Pt. I, this *J.*, 1935, p. 354), and the description of the root-system will therefore be given in accordance with the method used. The description which follows refers in the main to ordinary Uba. The superficial system was very extensive, by far the most extensive of all the varieties examined, not only as regards number of surface-roots but also as regards length and degree of branching. Six feet away from the stool there was a large number of roots, some of which were found even at this distance from the stool at a depth of 3½–4 ft. The longest superficial roots were, however, 12 ft. or more in length, branching profusely for 2–3 ft. from their terminations. There were few roots of this length. At 4 ft. from the stool there were not many more roots in the first 2 ft. of soil than at 6 ft., showing that relatively few roots terminate between 4 and 6 ft. The number of roots below 2 ft. is, however, markedly greater, passing down to depths of 4–5 ft., some being associated as rope-systems even at this distance from the stool and passing down to 7 ft. In one of these rope-systems there were twenty roots of various orders. The deeper roots were thicker and less branched than the superficial roots.

At 2 ft. away from the stool the number of roots was outstanding; the number in the first 2 ft. of soil was materially greater than at 4 ft. from the stool, showing that many roots only passed outwards to 2–4 ft. It was found that several of the roots actually ended in this region, whereas others merely passed outwards to this distance and then turned downwards. At 2 ft. from the stool numerous rope-systems passing down to depths of 8–10 ft. were encountered.

The final section at the edge of the stools showed very vigorous root-growth: there were some new white roots varying from a few inches to a foot in length emerging from the stool. Branching of the surface-roots was not nearly so prolific near the stool as at considerable distances away from it. Buttress-roots were extremely well developed, but were somewhat thinner and darker than usual. It is the rope-systems, however, which show their maximum development in this variety. Below a depth of 6 ft. very few roots were found that were not associated as rope-systems. Rope-systems were followed down to a depth of 18 ft.; at this

point there was a bed of rock, which made it impossible to continue the trench. The rope-systems turned inwards, following the face of the rock, so that their subsequent course could not be determined. There is little doubt, however, that the rope-systems of Uba pass down to a

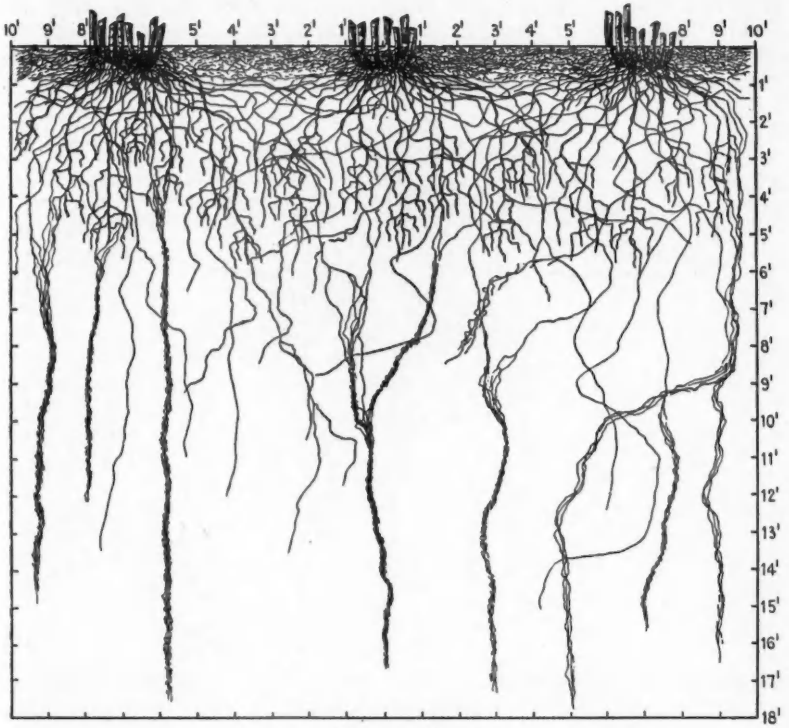

FIG. 3. Uba

depth of at least 20 ft. under these particular conditions of growth. So far as the author is aware, this is the greatest depth to which the roots of sugar-cane have been followed.

The root-systems of Uba Seedling, White Uba, Uba Seedling Brown Sport, &c., follow the same general distribution as that described above for ordinary Uba, but they are much less extensive than those of the parent type. In respect of number of roots, spread, degree of branching, &c., the Uba seedlings fall far short of ordinary Uba, though compared with some of the noble canes their root-system is markedly superior. The root-system of ordinary Uba is shown in section in Fig. 3.

Before leaving the Uba type of root-system, mention must be made of the variety Uba Marot. This cane was found in 1923 by Mr. L. Marot in a field at Gros Caillaux, Mauritius, and has proved to be of great value for breeding purposes. Its root-system is very extensive, but

different in several respects from the Uba type. The superficial roots are much thicker, more deeply seated, and less branched.

Roots belonging to the surface-system and passing out laterally are numerous to a depth of 2 ft. Among the preponderating thick surface-roots are shorter, thinner, and more branched roots, but the latter are few in this variety. Although certain of the surface-roots attain a length of 7–8 ft., the system has not nearly so large a spread as in Uba. Buttress-roots and rope-systems are numerous, but root-development below 5 ft.

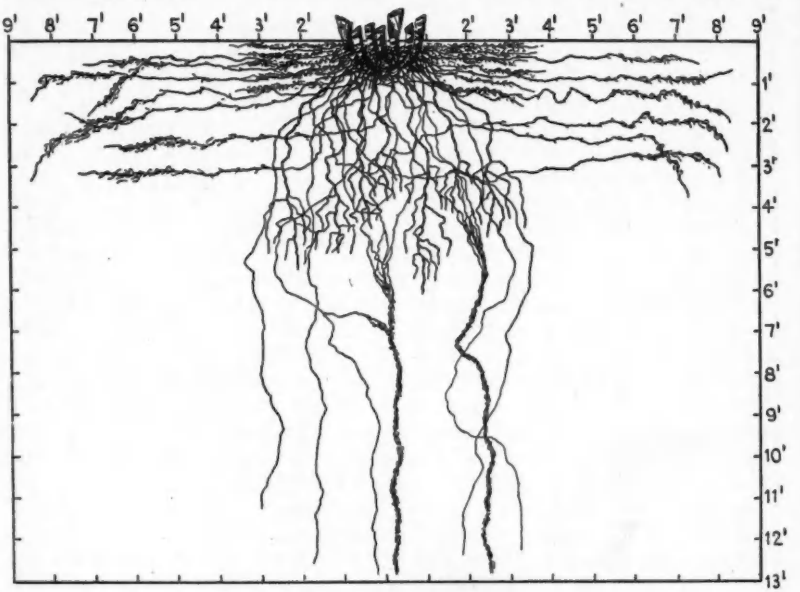

FIG. 4. Uba Marot

is not nearly so extensive as in Uba. The system as a whole shows several affinities to those of seedlings of the POJ. 2878×Uba Marot cross, and there is little doubt that Uba Marot has exerted a much stronger influence on the root-system of these seedlings than has the female parent, POJ. 2878. The root-system of Uba Marot is shown in Fig. 4.

The POJ Varieties

Although for convenience the varieties produced by the Proefstation Ost Java are grouped here under one heading, they show considerably more variation than do any of the other root-types considered in this paper, perhaps in part due to their origin from Chunnee or Glagah types, respectively. The POJ canes whose root-systems have been examined in detail include the following numbers: [POJ] 36, 213, 2940, 2878, 2727, 2747, 2364, and 161.

The root-system of POJ. 36 is comparatively superficial, the vast majority of the roots being present in the first foot of soil. The surface-roots show prolific branching, but do not attain great lengths. The buttress-system is adequately developed, but there are comparatively few rope-systems. POJ. 2747 and POJ. 2940 may be dealt with briefly here, since under Mauritius conditions both these varieties have a very meagre and poorly developed root-system.

In POJ. 2940 the roots are few and very superficial. Buttress-roots were present, and one rope-system was seen. The poor root-growth is

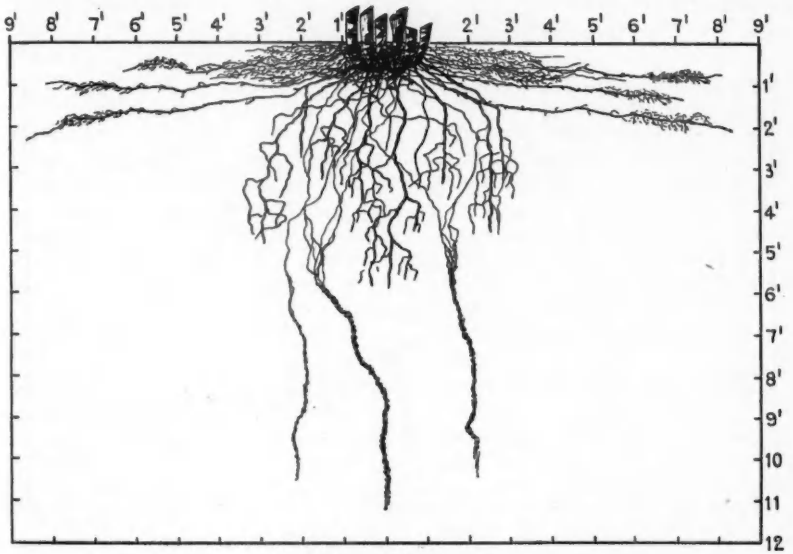

FIG. 5. POJ. 2727

correlated with comparatively poor top-growth consisting of large canes but very few in number. POJ. 2747 has a more deeply seated root-system than has POJ. 2940, but the roots are very short and few. The variety POJ. 213 has a very satisfactory root-system. It appears to be better balanced from the point of view of absorbing and anchoring than most of the noble canes. The superficial system is similar to that of POJ. 36, showing profuse branching, the roots being in the main comparatively short (up to 4 ft. long). In addition there are several longer surface-roots passing outwards at a depth of 6–12 in. and branching towards their terminations. The buttress-system is extremely well developed, the buttress-roots being much branched, but as in all cases of branching of the buttress-roots, the laterals are stout and not fibrous. There was a good average development of rope-systems, some passing down to 12–13 ft. Long, deeply seated rhizomes were common in this variety.

POJ. 2878 and POJ. 2727 have somewhat similar root-systems. The

superficial system is fairly extensive though not so much branched as in POJ. 36. POJ. 2878 is characterized by the thinness of the surface-roots, even the long main surface-roots being comparatively thin. Branching of the surface-roots is more marked in POJ. 2727, and some of the deeper surface-roots were longer and thicker than in POJ. 2878, some attaining a length of 8–9 ft. As the stools mature, both varieties have a tendency to form a large number of short superficial roots at or near the soil surface.

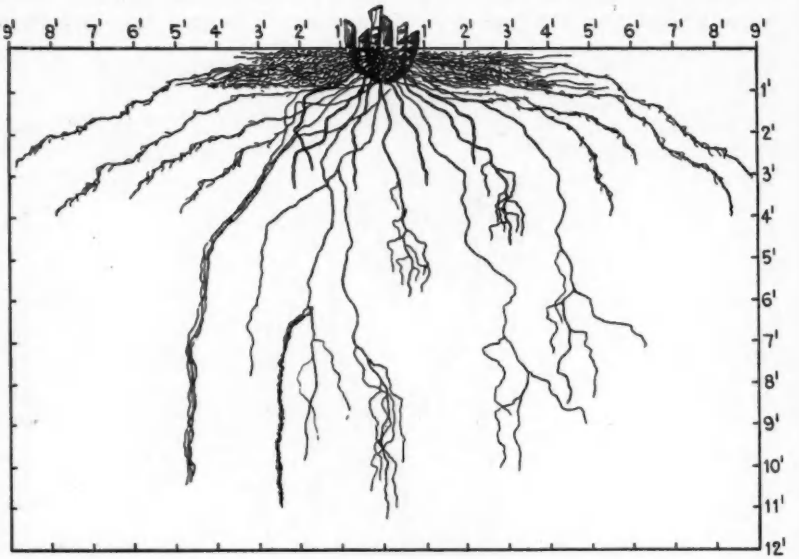

FIG. 6. POJ. 2364

The buttress-roots in POJ. 2878 were generally found descending to a depth of 4–5 ft., but immediately beneath the stool the buttress-roots were better developed and often reached a depth of 7 ft. These roots were normal in type. There were very few rope-systems.

In POJ. 2727 there was a stronger development of buttress-roots than in POJ. 2878; branching was also more prolific, and the buttress-roots showed to an extremely marked degree the distortions characteristic of these roots. Some rope-systems were also present, which at a depth of 8–9 ft. were still descending.

Considered as a whole, the root-system of POJ. 2878 though vigorous, is not outstandingly so. Jensen states that this variety has a tendency to produce roots in the upper soil-layers during the early part of the growth-period, the deeper roots developing later, so that in the mature plants they were almost as long as those of other varieties. There is little doubt, however, that POJ. 2727 (Fig. 5) has a superior root-system to POJ. 2878, though in distribution the root-systems of the two varieties show close similarity.

POJ. 2364 is a cane with a considerable amount of wild blood. It is unsuitable for commercial purposes, but invaluable for breeding, being the female parent of the famous POJ. 2878 and other good Java canes. As in most of the POJ canes the first 6 in. of soil contain many thin, profusely branching roots, but in addition there are other superficial roots which are thicker and branch only at considerable distances from the stool. Some of these longer superficial roots attain a length of 10 ft. They generally follow a horizontal course at a depth of 4–9 in., and some turn downwards to 1½–2 ft. towards their terminations. Groups of thick superficial roots often followed canals formed by insects to considerable depths (Fig. 6). These groups must not be confused with rope-systems, where the association is much more intimate.

The typical 'superficial' system is, in this variety, much more deeply seated than is normally the case, and appears to take the place of the buttress-system to a large degree; the normal buttress-roots are very few. Rope-systems, on the other hand, are quite well developed, and pass down to considerable depths. The system as a whole is thus very vigorous and deeply seated, making it probable that seedlings of this variety will not suffer from meagre root-development.

The variety POJ. 161 has an average root-system. The superficial roots extended to a distance of 6½–7½ ft. At 6 ft. from the stool there were no roots below 14 in. Branching was vigorous between 3 and 5 ft. from the stool. Buttress-roots were not numerous, but thick surface-roots similar to those described for POJ. 2364 passed down galleries formed by insects. Rope-systems were moderately well developed and were still descending at 7–8 ft.

Another (East Indian) variety which has a good root-system is Selangor Seedling; its surface-system is very similar to that of POJ. 2364, having long, thick surface-roots in addition to short thinner ones. Unlike POJ. 2364, however, it has a well-developed buttress-system, the buttress-roots being extremely thick, one of 1 cm. diameter having been found. The buttress-system is very similar to that of POJ. 2727, and, as in the latter variety, and in POJ. 2878, there is only a restricted development of rope-systems. Some of the other (East Indian) varieties studied, such as Penang, SW. 499, had very mediocre root-systems of the noble-cane type.

The Tanna Type

There are several forms of Tanna canes grown in Mauritius, the most widely cultivated being White Tanna. Among the Tanna canes whose root-systems have been investigated are White Tanna, Black Tanna, Striped Tanna, Tanna St. Aubin, and White Tanna Mon Desert. The variations in the root-systems within this class are comparatively insignificant. The root-system is peculiar in that roots are very numerous to a depth of about 2 ft.; but there is a well-marked line of demarcation at this point, very few roots indeed being found below 2 ft. (Fig. 7). The Tanna varieties differ in the number of roots in the first 2 ft., White Tanna having the most roots in this zone. Profuse branching near the stool is not at all common in this variety, only the younger, shorter roots

having this character. In general, the superficial roots are fairly thick and unbranched near the stool, but branch profusely towards their terminations. Several of the surface-roots took a downward course from their point of connexion in the stool, but at a depth of about 2 ft. changed their course and became horizontal, passing along at this depth either well down the interline or sometimes underneath adjacent stools and into the adjoining interline. Buttress-roots are numerous, but they also travel outwards, so that comparatively few reach a depth of 3–4 ft. White

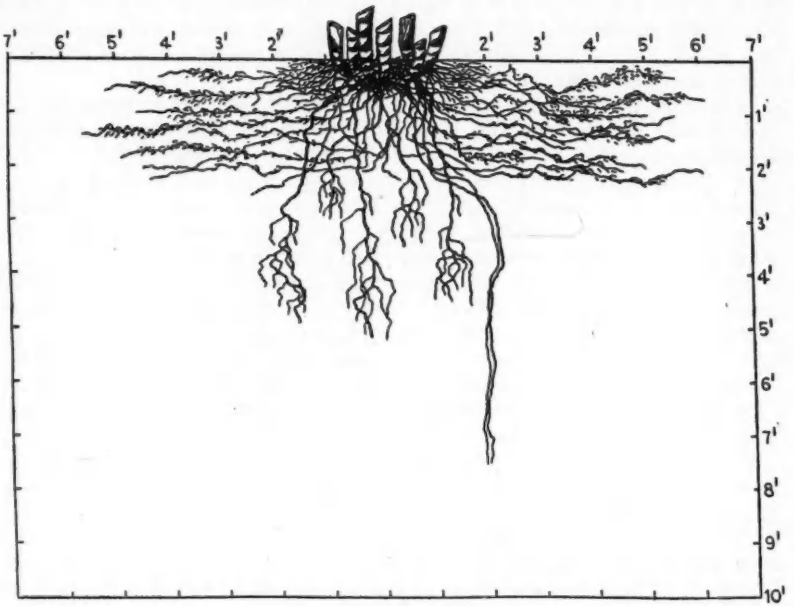

FIG. 7. White Tanna

Tanna, Black Tanna, and Striped Tanna conform accurately to this type, but some of the other Tanna varieties show slight differences. In Tanna St. Aubin the demarcation of roots between those in the first 2–2½ ft. and those below this depth is not so marked, and root-development in the surface-soil is not nearly so vigorous. There is, however, a slightly larger number of deeper roots, some buttress-roots attaining a depth of 5–6 ft. The best development of deeper roots occurs in White Tanna Mon Desert. In this variety, as in Tanna St. Aubin, the demarcation between the superficial and deeper roots is not so marked. The deep roots of this variety also are exclusively buttress-roots. Buttress-roots and their branches are fairly numerous to a depth of 5–6 ft. No rope-systems were encountered in the Tanna varieties. The system is an extremely good superficial system, but lacking in adequate formation of deep roots. This explains why most of the Tanna varieties are not suited to dry localities but perform remarkably well in the wet localities.

The Barbados Type

The typical example of the Barbados type of root-system is that of BH. 10(12) (Fig. 8). There are three other important West Indian varieties having a root-system that is sufficiently similar to be classified under the same heading, viz. SC. 12(4), D. 1135, and RP. 8. It is well known that in certain plants there is a correlation between the orientation of the leaves and the distribution of roots, the water dripping from the

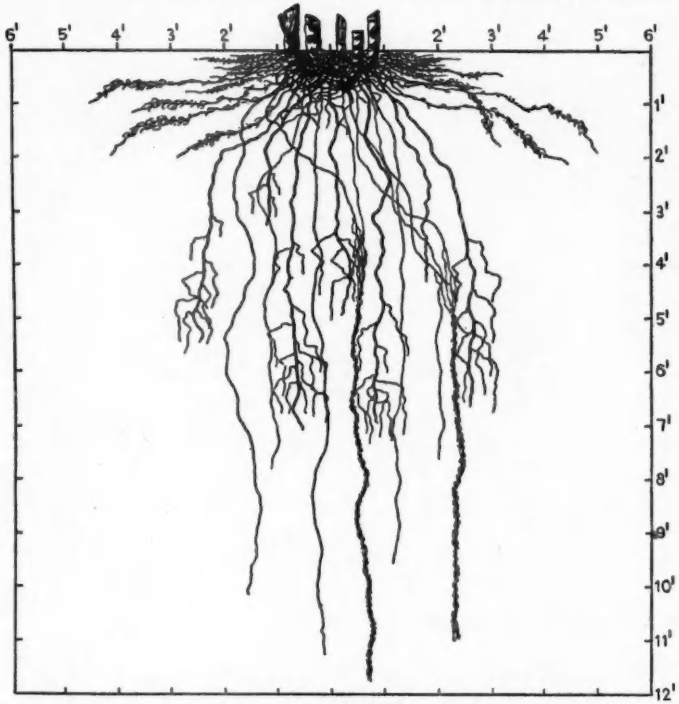

FIG. 8. Barbados BH. 10(12)

leaves being directed towards the absorbing region of the roots. Typical extremes are beet, with leaves orientated to direct water towards the tap-root, and the common nasturtium (*Tropeolum majus*), with leaves orientated to direct water towards the spreading fibrous root-system. The orientation of the leaves in the canes, here classified as the Barbados type, is characteristically different from what obtains in most of the other cultivated canes in Mauritius. The leaves stand more or less upright, and in accordance with this orientation the root-system is located much nearer the stool than is usually the case. In BH. 10(12) the extent of the superficial system is comparatively restricted; the number of roots is also smaller than usual and more sparsely branched. Superficial roots are, in the main, up to 2 ft. long, though a few reached 4–5 ft. Buttress-

roots were very numerous and descended more or less downwards beneath the stool to a depth of 6–7 ft. Rope-systems were fairly numerous but not of a very elaborate type, and descended to a depth of about 10 ft. Most of the roots of this variety had an oldish and very dark appearance, and there were very few new roots, either main roots or branches, with the exception of a few root-primordia just below the soil-surface that had germinated to give rise to young white roots. The distribution of roots is thus very satisfactory, root-development having taken place to considerable depths. The system, when examined, however, appeared to lack vigour and vitality, although this might have been an abnormal condition due to some unknown local factor.

The root-system of SC. 12(4) is similar in essentials to that of BH. 10(12). It shows a more vigorous development of superficial roots, though in this case also the spread is small, the system being situated close to the stool. Buttress-roots are very well developed, descending to 6–7 ft. The development of rope-systems was not so pronounced as in BH. 10(12), only a few rudimentary rope-systems being seen. There is thus less extensive root-growth in the deeper soil-layers in SC. 12(4), as compared with BH. 10(12). In D. 1135 also the superficial system consists of relatively short roots with a few longer roots at a greater depth. Buttress-roots were well developed but passed more or less vertically downwards and did not spread outwards to any marked degree. They attained depths of 6 ft. Rope-systems were few and very rudimentary, having only 2 to 3 roots in association. Branching of all the root-types is very sparse. The system is thus very similar to that of BH. 10(12) and SC. 12(4), but more restricted in its growth.

RP. 8 also has a very similar type of root-system; the surface-system is rather deeply seated and located in close proximity to the stool. Buttress-root development is stronger than in most varieties. The root-systems included here under the heading of the Barbados type are thus similar, in that they show a reduced superficial system situated very near the stool, accompanied by vigorous formation of deeper roots located for the most part directly beneath the stool.

Mauritius Noble Seedling Types

Several of the older noble canes bred in Mauritius that have become of some commercial value have been examined. These include the 1916 seedlings M. 20/16, M. 23/16, M. 27/16, and M. 29/16; also M. 13/18, M. 7/23, M. 14/26, M. 109/26, and M. 55/1182. There is nothing out of the ordinary in these root-systems, all the varieties having a root-system of the typical noble-cane type but with variations according to the variety. The noble-cane type exemplified by these varieties is a comparatively shallow system. Sixty per cent. or more of the roots is found in the first foot of soil, and the number of roots reaching below 4 ft. is negligible. The superficial system is generally very extensive, the roots being 6–7 ft. long and branching profusely towards their terminations. Buttress-roots are common in all these varieties, but generally they are not outstanding in their development. There are considerable differences in

the mean diameter of the roots in these noble canes, the magnitude of the differences involved being seen from the following table:

	Mean diameter of roots	*Standard error of mean*
M. 13/18 . . .	1·91 mm.	0·014
M. 14/26 . . .	1·28 „	0·003
M. 7/23 . . .	1·79 „	0·007

M. 109/26 was characterized by vigorous formation of buttress-roots, even very young shoots with no unfolded leaves bearing 8 to 10 thick

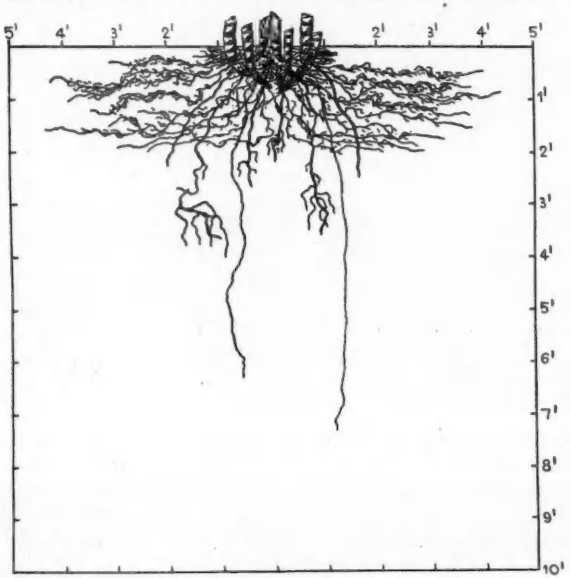

FIG. 9. M. 23/16

buttress-roots. Among these noble-cane types, the best root-systems were found in M. 109/26, M. 23/16, and M. 27/16. Examples of this type of root-system are shown in Figs. 9 and 10.

Miscellaneous Noble-cane Types

Among the other noble canes grown commercially in Mauritius whose root-systems have been examined in detail are RP. 6, ordinary and striped, DK. 74, DK. 74/70, and among the old cultivated varieties that have gone out of cultivation because of susceptibility to diseases, Sealy's Seedling, Rose Bambou, and Port Mackay. These were examined mainly to find varieties with suitable root-systems for breeding-work. All these varieties have root-systems of the noble-cane type, Port Mackay being characterized by very thick roots. The root-system of RP. 6 was somewhat below average in its development.

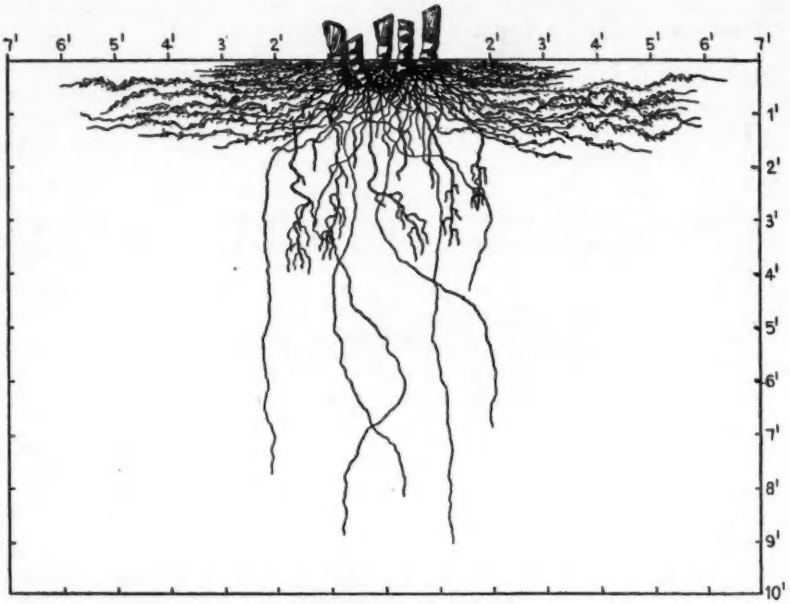

FIG. 10. M. 27/16

Summary

The root-systems of several varieties of sugar-cane have been examined in detail with a view to selecting canes of satisfactory root-growth for breeding and for cultivating under various environmental conditions prevailing in Mauritius. The nature of the root-systems enables one to indicate what canes are likely to do well in dry localities, in very wet localities, and in localities heavily infested with the root-eating grubs of *Phytalus Smithi*. It is also possible to indicate the degree of cyclone-resistance from the nature of the root-system. Data on the root-systems also provide a basis on which to evolve programmes for fertilizer application and various cultural practices. The data included in this paper represent a bare statement of the essential features of sugar-cane root-systems. In a later paper further information on various aspects of root-growth in sugar-cane, and the practical application of the results, will be considered.

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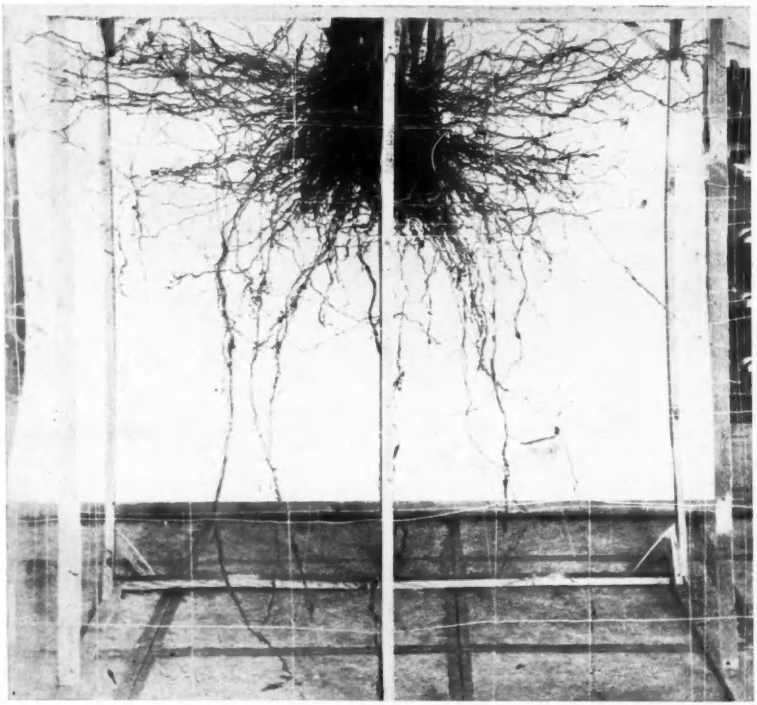

FIG. 1. The Root-system of a First-nobilized Glagah seedling

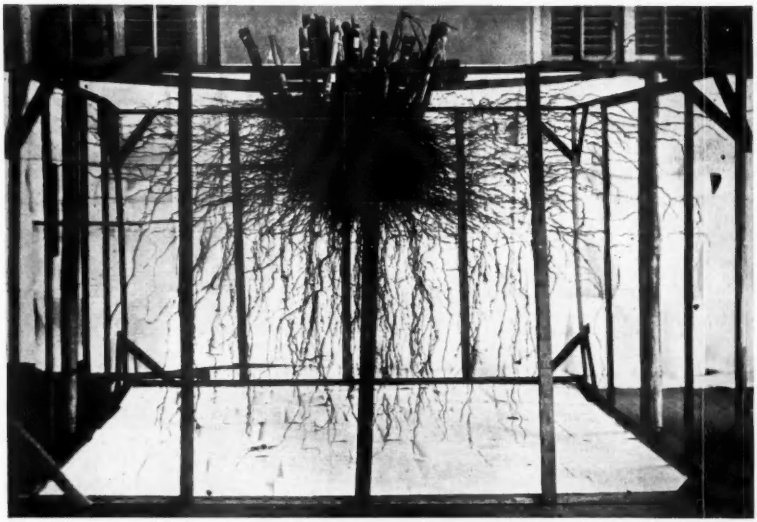

FIG. 2. Root-system of a POJ. 2878 × Uba Marot seedling

THE AGRICULTURALLY IMPORTANT SOILS OF BURMA

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BURMA is the largest province of the Indian Empire; excluding the Shan States and Karenni State, it occupies 184,102 square miles. A great deal of this area is covered by forests. The cultivated area was 17·2 million acres in 1933–4 [1], and in it alluvial soils vastly preponderate.

Inspection of a physical map of Burma will show that the country may be divided into: (1) the narrow Arakan coastal strip; (2) the Arakan Yoma mountain range and its extensions to the north and south; (3) the central belt consisting of the basins of the Rivers Chindwin, Irrawaddy, and Sittang; (4) the Shan Plateau and the mountains extending north and south from it; and (5) the narrow coastal strip in the south-east consisting of the Tenasserim Division [2].

Except for small areas in the coastal strips and the Shan Plateau, the important agricultural soils of Burma are situated in the central belt.

Climate [3].—The central belt can be divided into three portions on the basis of rainfall: (*a*) the northern region, roughly between 23° N. and 26° N., receives an annual rainfall of 40–90 in.; (*b*) the middle portion, known as the Dry Zone, between latitudes 23° N. and 19° N., with an annual rainfall of 20–40 in.; and (*c*) the southern portion, lying between latitudes 19° N. and 15° N., and receiving 80–200 in. of rainfall annually. This portion includes the whole of the Irrawaddy Delta and the basin of the River Sittang.

The rainfall of Burma is almost entirely derived from the south-west monsoon and is therefore practically confined to the period April to October. The greatest fall is in June to September. The rains cause severe floods and it is common to have immense areas of cultivated land under water in the rainy season.

The temperature is highest during April and May, reaching 100° F. or more in parts. When the rains set in the temperature falls somewhat but still remains high. During November the temperature begins to fall still further and remains low during the period November to February, at the end of which it rises again.

Topography.—For 200 miles south of Myitkyina in the extreme north of the northern section, the agricultural land lying between the hills on either side of the railway and rivers is barely more than 10 miles wide, and it is only in the southern 100 miles that the valleys widen to a gently undulating plain some 30 miles wide. The Dry Zone is a low-lying plain much cut up by ravines. The southern section is also a level plain, except for the Pegu Yoma Range, which divides the basins of the Irrawaddy and the Sittang rivers.

Floods are therefore frequent throughout the central belt. The principal railway line runs from Myitkyina in the extreme north to Rangoon in the south. The line follows the river valleys, so that breaches in the railway line during the rainy season are a common occurrence in Burma.

The low-lying soil of the whole belt is almost uniformly fine-textured,

so that drainage by percolation is practically non-existent. The only possible means of drainage is by surface run-off. The level topography restricts even this form of drainage. The result is that extensive areas are waterlogged during the rains. These areas are therefore suited only for the growth of paddy.

Geology [4].—In the northern section of the central belt small areas are occupied by old hard rocks, chiefly granite, gneiss, and limestone. The bulk of the belt is, however, covered by alluvium. The texture of the alluvium is generally heavy, although sandy material occurs in places, especially near the river banks ('non mye,' i.e. riverine silts).

The Soil Types

A systematic study of the soils of Burma from the standpoint of pedology has not been made. The information gathered so far has been obtained in studies of soil fertility and in advisory work. For practical reasons the soils that have been studied in the central belt were taken from places not far from the railway line. Large areas to the west of the Irrawaddy have not yet been studied.

The soils of the central belt may be classified as follows:

A. Soils with Impeded Drainage—

1*a*. Formed in arid climate, and containing calcium carbonate accumulation in the profile ('regur'). These approach the Solontschak type, e.g. in Mandalay, Singaing.

1*b*. Similar to those in 1*a* but with a slight accumulation of sodium salts, e.g. in Padu.

2. Formed in a wet climate with a rainfall of 80 in. or more, e.g. in Hmawbi.

B. Soils with Good Drainage—

1. Formed in an arid climate, e.g. Padu (Red), Kanbalu. The molecular ratio SiO_2/Al_2O_3 for the clay-fraction of these soils is greater than 2·0. They are therefore non-lateritic, and are probably akin to the red earths.

2. Formed in a wet climate with a rainfall of 80 in. or more. The clay-fraction of such soils shows a SiO_2/Al_2O_3 molecular ratio ranging between 1·7 and 2. These soils are therefore lateritic [5].

Analytical Methods

The composition of the whole soils was determined by boiling with conc. HCl for 8 hours on the sand-bath and analysing the extracts. The clay-fraction was separated by treatment with sodium hypobromite followed by dispersion with ammonia. The sedimentation was carried out in beakers, the clay being poured off to a depth of 8·4 cm. after standing for 24 hours. After flocculation with dilute HCl, the clay was filtered off, dried, and analysed by fusion with sodium carbonate in nickel crucibles. Only routine methods were used in the determinations. No great accuracy is therefore claimed for the silica—sesquioxide or silica—alumina ratios of the clay-fraction. All such ratios given in the various Tables are molecular ratios.

DESCRIPTION OF TYPES

A. Soils with Impeded Drainage

1a. Formed in an arid climate.

Mandalay Soil: Latitude 22° N.; longitude 96° 5′ E.
Geology: Recent Alluvium. Very deep.
Rainfall: 30 in. Drainage poor.
Topography: Level.

Soil pits show this soil to consist of a dark humus-containing horizon about 3 ft. deep, with small light-coloured nodules of calcium carbonate. This horizon is grey or greyish-black when dry and almost black when moist. At about 3 ft. depth the humus-layer ceases and is replaced by a yellow horizon containing relatively large amounts of calcium carbonate. This horizon extends down to about 8 ft. Below this lies a horizon of yellow clay. The soil was not examined below 12 ft. At 3 ft. 8 in. the nodules were of considerable size, the maximum amount occurring at 4–7 ft., where they form a layer commonly called 'kankar'. Table 1 gives the amount and composition of kankar in the profile [6].

TABLE 1. *Kankar in Mandalay Soil Profile*

Depth in feet	*Stones and gravel 2 mm. diameter (kankar) per cent.*	*Composition of kankar (per cent.)*				
		CaO	MgO	Na_2O	MnO	CO_2
A Horizon						
0–0·5	0·6	39·2	0·2	0·5	0·9	16·5
0·5–1	0·3	39·5	0·3	0·7	0·6	16·1
1–2	1·8	40·9	0·3	1·0	0·8	25·5
2–3	3·3	39·6	0·2	0·8	0·8	16·5
B Horizon						
3–4	8·0	34·2	0·4	2·6	0·6	17·0
4–5	9·8	32·1	0·5	3·5	0·8	18·1
5–6	10·6	33·6	1·2	2·2	1·1	19·9
6–7	7·8	28·3	3·2	1·9	1·1	18·8
7–8	5·5	32·4	1·9	1·2	0·2	18·2
C Horizon						
8–9	3·3	28·2	0·8	1·3	0·2	20·2
9–10	2·6	25·0	0·8	1·3	0·2	19·4
10–11	2·0	26·3	0·8	0·8	0·1	20·6
11–12	2·1	29·3	2·2	0·1	0·2	19·6

The analyses quoted show that the soils of this group belong to the Carbonate Solontschak type. There has been no leaching of humus from the surface-soil downwards, probably because the concentration of electrolytes in the surface-layers is sufficient to prevent it. The B horizon is slightly compacted and contains a considerable accumulation of calcium carbonate. Under paddy-cultivation it has been noticed that the humus-content of the A horizon decreases. The $CaCO_3$-content of the B horizon also decreases.

TABLE 2. *Analysis of Mandalay Soil (Dry Cultivation Area)*

Depth in feet	pH	Soluble in conc. HCl (per cent.)					Org. Carbon per cent.	Clay-fraction	
		Fe_2O_3	Al_2O_3	CaO	MgO	Na_2O		$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Al_2O_3}$
A Horizon									
0–0·5	8·05	3·26	8·65	0·85	0·91	0·51	0·60	2·24	2·71
0·5–1	8·05	3·34	8·68	1·19	0·88	0·51	0·35	2·16	2·63
1–2	8·22	6·70	8·54	1·35	0·94	0·58	0·23	2·15	2·61
2–3	8·40	4·64	9·58	2·02	0·93	0·87	0·24	2·25	2·73
B Horizon									
3–4	8·65	5·20	9·12	2·71	0·52	0·99	0·22	2·37	2·88
4–5	8·93	5·35	10·34	2·39	1·04	0·86	0·21	2·32	2·82
5–6	9·04	4·96	10·33	2·95	1·54	0·92	0·16	2·31	2·81
6–7	9·09	4·96	10·05	2·64	1·71	0·98	0·18	2·23	2·75
7–8	9·10	4·92	9·28	2·12	1·67	0·99	0·14	2·28	2·81
C Horizon									
8–9	9·00	5·15	9·51	1·28	1·62	0·99	0·09	2·19	2·69
9–10	8·86	5·15	9·39	0·83	1·51	0·75	0·09	2·07	2·60
10–11	8·68	4·92	9·42	0·72	1·25	0·86	0·08	2·02	2·47
11–12	8·68	5·63	9·07	0·65	1·42	0·96	0·05	1·92	2·29

The soils in the Dry Zone have been cultivated for long periods, so that profile-development under natural conditions has been hindered. These soils crack very strongly in the rainless months, the cracks being several feet deep. This behaviour again prevents a normal development in the profile. Vageler states [7] that these cracks in tropical soils tend to render them homogeneous by circulation.

The Mandalay soil type bears a close resemblance to the black-cotton soil of India [8].

Singaing Soil: Kyauksé district: Latitude 21° 45′ N.; longitude 96° 9′ E. On the railway line.
Geology: Recent Alluvium.
Rainfall: 30 in.
Topography: Level.

TABLE 3. *Analysis of Singaing Soil*

Depth (inches)	0–13	13–26	26–48
Coarse sand %	2·70	1·30	1·25
Fine sand %	21·00	19·05	19·55
Silt %	23·18	24·48	24·35
Clay %	43·05	46·20	46·30
pH	8·5	8·2	8·7
CaO % sol. in HCl	4·15	3·14	3·43
MgO % ,, ,,	1·48	1·69	1·75
Na_2O % ,, ,,	0·76	0·98	0·97
SiO_2/R_2O_3 in clay-fraction	2·28	2·31	2·39
SiO_2/Al_2O_3 ,,	2·82	2·81	2·90

A. 1*b*. *Soils with impeded drainage formed in an arid climate and showing the presence of sodium salts.*

Padu Black Soil: Sagaing district: Latitude 22° 5′ N.; longitude 95° 58′ E.; situated on the railway line from Mandalay to Myitkyina.

Geology: Recent Alluvium.

Rainfall: 25 in. Drainage poor.

Topography: Level.

The Padu Black soil is a very stiff tenacious clay that forms deep cracks in the dry season. The chief crops are gram and wheat. This soil is cultivated in the dry spells from July onwards. Round Padu Lake the cultivators may never be able to start until October owing to poor drainage, but such a method of working is exceptional. Actually most of the cultivation is done during the rains. Crops are not sown, however, until the end of the rains.

The Padu Black soil is blacker in colour when wet than is the Mandalay soil. The water-extract of the Padu Black soil contains organic matter in solution, an indication that the soil contains much exchangeable sodium, whereas the water-extract of the Mandalay soil does not contain organic matter, probably because this soil is rich in exchangeable calcium. The analysis of Padu soil (Table 4) shows the relatively high content of sodium compared with that of calcium.

TABLE 4. *Analysis of Padu Black Soil*

Depth (inches)	*0–6*	*6–24*	*24–48*
Coarse sand %	12·5	11·3	10·5
Fine sand %	9·7	10·6	10·3
Silt %	15·3	15·2	14·8
Clay %	56·0	57·6	59·0
pH	7·85	7·95	8·25
CaO % sol. in HCl	0·88	0·80	0·64
Na_2O % „ „	0·97	1·03	1·31
Organic carbon %	0·43	0·40	0·34
Nitrogen %	0·05	0·04	0.04
SiO_2/R_2O_3 in clay-fraction	2·43	2·44	2·57
SiO_2/Al_2O_3 „	2·97	3·01	3·17

Chiba Soil: Shwebo district: Latitude 22° 34′ N.; longitude 95° 54′ E. About 3 miles south-west of Shwebo town.

Geology: Recent Alluvium.

Rainfall: 30 in. Drainage fair, as the soil is coarse-textured.

Topography: Level.

The soil is a sandy loam showing saline inflorescence in the dry season. Such saline soils are common near Shwebo and are known as 'hsatpya'. The chief constituent seems to be sodium sulphate.

There is a striking difference between the soils in the southern portion of the Dry Zone and those in the northern portion, the dividing line between the two portions being the River Irrawaddy. The soils in the south, e.g. Mandalay and Singaing, are rich in calcium and magnesium and relatively low in sodium. On the other hand, the soils in the northern

portion of the Dry Zone, e.g. Padu Black and Chiba, are low in calcium and magnesium but contain a relatively high proportion of sodium. Saline inflorescence is common in this area, the chief salts being sulphates, although the soil of the Chiba farm does not show this inflorescence.

TABLE 5. *Analysis of Chiba Soil*

Depth (inches)	*0–9*	*9–28*	*28–40*	*40–48*
Coarse sand %	42·9	41·8	35·0	38·1
Fine sand %	24·3	20·8	29·7	25·8
Silt %	13·0	14·1	12·3	13·2
Clay %	18·5	21·8	18·5	21·8
pH	6·6	7·85	9·1	9·1
CaO % sol. in conc. HCl	0·20	0·33	0·40	0·46
Na_2O % „ „	0·39	0·42	0·48	0·37
SiO_2/R_2O_3 in clay-fraction	2·64	3·05	3·02	3·06
SiO_2/Al_2O_3 „	3·17	3·69	3·66	3·72

A. 2. *Soils with impeded drainage formed under a high rainfall.*

Hmawbi Paddy Soil: Latitude 17° 6′ N.; longitude 96° 5′ E. On the railway line from Rangoon to Prome.

Geology: Old Alluvium.

Rainfall: 95 in. Marshy conditions from May to November; the permanent water-table is only 7½ ft. below the surface.

Topography: Level.

TABLE 6. *Analysis of Hmawbi Paddy Soil*

Depth (feet)	*0–0·5*	*1–2*	*4–5*	*6–7*	*7–8*	*8–9*	*9–10*	*10–11*	*11–12*
Coarse sand %	1·3	1·4	0·9	0·5	0·5	2·5	4·4	14·9	7·1
Fine sand %	10·2	8·5	5·9	5·1	6·2	12·1	17·9	21·4	24·4
Silt %	60·7	42·9	35·8	41·0	40·4	41·2	38·7	34·9	34·5
Clay %	24·5	45·3	53·5	48·8	47·0	40·6	34·5	26·9	30·6
pH	5·6	5·4	6·05	6·15	6·25	6·25	6·05	5·5	5·5
Al_2O_3 % sol. in conc. HCl	5·3	9·1	11·6	11·7	11·4	10·1	7·6	6·8	7·7
CaO % „ „	0·15	0·21	0·22	0·19	0·26	0·21	0·16	0·13	0·13
MgO % „ „	0·13	0·17	0·55	0·44	1·28	0·92	0·45	0·31	0·25
SiO_2/R_2O_3 in clay-fraction	1·97	2·12	1·88	2·16	2·04	2·08	2·16	2·13	2·96
SiO_2/Al_2O_3 „	2·14	2·34	2·11	2·58	2·58	2·54	2·43	2·44	2·20
Total exchangeable bases in m.eq. held by 100 gm. of soil	5·9	11·3	18·1	19·6	12·7	12·3	8·8	5·6	4·9

TABLE 7. *Analysis of Hmawbi Soil from Grazing Ground (Uncultivated)*

Depth (feet)	*0–0·5*	*0·5–1*	*1–2*	*2–3*	*3–4*	*4–5*	*5–6*
Coarse sand %	0·8	0·8	1·5	1·8	3·9	9·7	52·5
Fine sand %	19·1	15·5	15·2	14·5	38·9	66·6	43·0
Silt %	32·7	31·3	35·5	41·7	28·9	11·0	2·6
Clay %	41·4	47·1	43·0	39·3	25·4	11·4	1·9
pH	5·65	6·05	7·2	7·5	7·25	6·6	6·5
Al_2O_3 % sol. in conc. HCl	9·9	9·3	11·5	11·8	8·7	5·5	3·2
Fe_2O_3 % „ „	3·7	4·6	6·1	6·5	5·3	3·9	2·3
Organic carbon %	1·79	1·34	0·67	0·39	0·29	0·15	0·05
Nitrogen %	0·16	0·11	0·06	0·04	0·04	0·02	0·01
SiO_2/R_2O_3 in clay-fraction	2·18	2·04	1·97	2·14	2·08	..	2·15
SiO_2/Al_2O_3 „	2·52	2·36	2·34	2·61	2·52	..	2·60
Exchangeable bases per cent. in m.eq.	12·5	20·3	20·3	25·0	21·1	11·0	6·1

The Hmawbi soil (Table 6) is the typical paddy soil of the Delta of the Irrawaddy, and hence is by far the most important type of soil in Burma. This soil cracks in the dry weather just like the soil of the Dry Zone (Mandalay, Padu). The dry surface-soil is a light yellow, becoming a deeper yellow in the B horizon. The permanent water-table is at about 7½ ft. below the surface. Near this zone and below, the soil has a bluish colour due to the presence of ferrous iron, probably in the form of sulphide. This is the only obvious horizon change, because organic matter shades imperceptibly.

The B horizon is more compact than the A and C horizons, probably owing to the transfer of finer material from the surface. The B horizon is also a zone of concentration (cf. the data for pH, Al_2O_3 and Fe_2O_3 soluble in HCl, and exchangeable bases). This concentration would be expected from the heavy rainfall, which would cause a downward leaching, and from the capillary rise from the water-table in the C horizon in the dry season. These two movements are likely to be impeded by the heavy-textured B horizon.

B. 1. *Soils with good drainage formed under an arid climate.*

This type of soil occurs in the Dry Zone. The improved drainage is caused by the location of such soils on slopes and by their coarse texture. When the soil is deficient in organic matter its colour is red (Padu Red), but when sufficient organic matter is present the colour is dark (Kanbalu). The improved drainage is reflected in the pH values, which indicate a neutral or slightly acid reaction, instead of the decided alkaline reaction shown by the associated soils with impeded drainage.

TABLE 8. *Analysis of Padu Red Soil*

Depth (inches)	*0–6*	*6–24*	*24–48*
Coarse sand %	55·0	39·2	29·4
Fine sand %	33·1	21·4	22·3
Silt %	4·3	6·4	9·6
Clay %	8·8	33·2	36·4
pH	6·1	6·1	6·7
Organic carbon %	0·17	0·29	0·23
Nitrogen %	0·04	0·06	0·05
Al_2O_3 % sol. in conc. HCl	1·77	8·52	8·48
CaO % " "	0·08	0·18	0·24
Na_2O % " "	0·21	0·43	0·33
SiO_2/R_2O_3 in clay-fraction	2·13	1·89	1·91
SiO_2/Al_2O_3 "	2·62	2·29	2·28

Kanbalu Soil: Latitude 23° 12′ N.; longitude 95° 35′ E. Situated on the railway line from Mandalay to Myitkyina, between the River Mu and the River Irrawaddy.
Geology: Recent Alluvium.
Rainfall: 45 in. Drainage good.
Topography: Undulating.

TABLE 9. *Analysis of Kanbalu Soil*

Depth (inches)	*0–13*	*13–25*	*25–37*	*37–48*
Coarse sand %	57·7	44·0	36·9	40·8
Fine sand %	15·0	13·1	17·9	29·2
Silt %	6·4	5·6	11·4	9·7
Clay %	20·0	33·5	30·9	18·9
pH	6·15	6·05	6·5	6·2
Organic carbon %	0·68	0·42	0·27	0·17
Nitrogen %	0·07	0·05	0·05	0·04
Al_2O_3 % sol. in conc. HCl	5·1	9·0	9·0	8·8
CaO % " "	0·20	0·25	0·62	1·16
Na_2O % " "	0·05	0·50	0·58	0·55
SiO_2/R_2O_3 in clay-fraction	2·47	2·14	2·29	2·38
SiO_2/Al_2O_3 "	2·98	2·53	2·71	2·88

The SiO_2/Al_2O_3 ratios in the soil type represented by Padu Red and Kanbalu are higher than 2. These soils may be regarded as akin to the red earths [7, 9].

B. 2. *Soils with good drainage formed under a heavy rainfall.*

These soils are of the lateritic type. They are found in the Irrawaddy Delta and in the coastal strips receiving a heavy rainfall. The water-table in these soils is very far below the surface or does not exist at all. In fact laterite-formation appears to cease at the water-table. The drainage is favoured by their location on slopes. Soils of this type are highly leached, as may be seen from the very low percentages of exchangeable and acid-soluble bases, and the high acidity, as indicated by low pH values (Tables 10, 11). These soils are usually adapted to the growth of rubber and fruit-trees or evergreen forest.

TABLE 10. *Analysis of Hmawbi Garden Laterite Soil*

Depth (feet)	*0–1*	*1–6*	*6–9*
Coarse sand %	56·3	38·8	37·6
Fine sand %	19·3	23·8	23·0
Silt %	7·7	10·1	14·2
Clay %	15·0	27·3	24·1
pH	5·3	5·3	5·2
Al_2O_3 % sol. in conc. HCl	4·04	8·21	8·18
Fe_2O_3 % " "	1·24	2·21	3·89
CaO % " "	0·02	0·03	0·03
MgO % " "	0·01	0·02	0·02
SiO_2/R_2O_3 in clay-fraction	1·71	1·75	1·58
SiO_2/Al_2O_3 "	2·01	2·03	1·76
Exchangeable bases per cent. in m.eq.	2·0	1·5	2·0

The SiO_2/Al_2O_3 ratios of the clay-fraction of this type of soils range between 1·7 and 2·0. The soils can therefore be regarded only as lateritic. Probably the absence of rains for 6 months in the year prevents the formation of laterite.

TABLE II. *Analysis of Hmawbi Virgin Laterite (Evergreen Forest)*

Depth (feet)	*0–1·15*	*1·75–3*	*3–4*	*13–14*	*23–24*
Coarse sand %	24·8	19·7	10·7	34·9	43·8
Fine sand %	50·5	34·7	42·1	26·4	31·0
Silt %	9·4	17·1	16·5	13·8	17·9
Clay %	14·5	27·7	29·7	24·4	6·3
pH	5·1	5·4	5·3	5·35	5·5
Al_2O_3 % sol. in conc. HCl	4·32	8·93	8·53	9·88	7·37
Fe_2O_3 % „ „	1·43	4·06	4·36	3·82	3·10
CaO % „ „	0·06	0·03	0·03	0·02	0·02
MgO % „ „	0·07	0·12	0·12	0·02	0·02
SiO_2/R_2O_3 in clay-fraction	1·60	1·61	1·60	1·63	1·49
SiO_2/Al_2O_3 „	1·92	1·86	1·87	1·84	1·85
Exchangeable bases per cent. in m.eq.	1·2	2·1	1·5	1·7	1·2

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SOME EFFECTS OF DROUGHT ON POTATO TUBERS

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With Plates 14, 15

Introduction.—During the dry summer of 1933 potato plants showed many indications of injury from drought at Glasnevin. The plants (variety Up-to-Date) in a spraying experiment consisting of many small plots all appeared pale and somewhat wilted in August and September, but the 26 randomized plots sprayed with proprietary mixtures and the 5 unsprayed plots obviously suffered more than the 13 plots sprayed with Burgundy mixture. This was mainly due, not to the better blight control in the last case, but to the slightly stunted leaf-apparatus of the plants withstanding the drought better than the initially more luxuriant foliage on the other plants.

These plots consisted of three drills bounded by a vacant drill on each side, and the effect of the drought was also shown by the more luxuriant appearance of the outer drills and their higher yield, which amounted to 27 per cent. on the average. This contrast occurred throughout the plots, although it was least marked where Burgundy mixture had been used, and was due to the greater amount of root-run provided for the outer plants and the additional water thus made available. On one only of the 32 plots did a centre drill give a higher yield than either of the outer ones. The same phenomenon is observable in other years, but to a less extent, because soil moisture is not usually a limiting factor.

These observations make clear the serious nature of the water-shortage in the latter part of 1933. There were two hot and dry periods, viz. from the end of July to about Aug. 22, and from early September to Sept. 17, and the effect on the foliage was most severe at the end of these two periods. The effects, however, were not confined to the foliage, for the tubers also were proved to have been affected by the drought. The weather of 1933 is shown in Table 1. The summers of 1934 and 1935, apart from September, were also dry, and as potatoes showed some drought effects in these years also, weather records referring to them are included in the table.

EXPERIMENTAL

With particular reference to Tuber-softening and Premature Sprouting

In digging an adjacent plot of President potatoes on Sept. 28 and 29, 1933, most of the plants, approximately 250 in number, had apparently normal tubers, but those belonging to about 10 plants were perceptibly soft. Usually all the tubers of a plant were affected, more especially the larger ones, but sometimes only a single tuber was abnormal. The softness was not due to decay, for microscopic examination and cultural experiments showed that parasites were absent. The tubers came out of the ground dry and clean, unlike those affected by such diseases as pink rot and black leg, which also give rise to soft tubers, and most of

them were still attached to the stalk by sound stolons. The softness was in some cases confined to the heel-end, but in others the whole tuber was involved. Usually it was necessary to handle the affected tubers, which had a rubbery feel, before their condition was discovered, but

TABLE 1. *Weather Records at Glasnevin 1933, 1934, 1935*

	Shade temp. (° F.)			*Rainfall* (mm.)		*Sunshine* (hours)	
Period	*Absolute max.*	*Mean*	*Deviation*	*Total*	*Deviation*	*Daily mean*	*Deviation*
1933 June	75	57·8	+1·6	40	−11	4·77	−1·53
July	81	63·1	+3·9	48	−17	5·52	+0·04
Aug.	79	62·1	+3·6	18	−64	6·25	+1·02
Sept.	75	57·7	+2·9	22	−29	5·13	+0·50
1934 June	77	59·3	+3·5	39	−12	6·76	+0·57
July	80	63·0	+3·6	46	−19	7·01	+1·46
Aug.	75	58·7	0·0	81	−1	4·66	−0·36
Sept.	72	57·1	+2·2	78	+27	4·78	+0·35
1935 June	76	57·7	+1·9	73	+22	5·74	−0·45
July	79	60·9	+1·5	21	−44	6·94	+1·39
Aug.	77	60·9	+2·2	58	−24	5·34	+0·32
Sept.	69	55·5	+0·6	97	+46	4·14	−0·29

others were visibly shrivelled. Most of the plants which produced these tubers were dead at the time of digging, but a few were still green and the majority were known to have suffered from virus diseases, for the potatoes belonged to a poor commercial lot. In addition to some leaf-roll and various mosaics, the principal virus present was a yellow mosaic related to the tuber blotch virus of Loughnane and Clinch [1], which spread considerably during the year. It is concluded on other grounds that this affects transpiration, and as it was certainly present in the worst cases, though not in all, it appears to have been an aggravating factor.

Drought was clearly the cause of the injury. Certain plants in their extreme need had drawn on the water-supply of the tubers, no doubt in order to eke out the existence of the aerial parts, but most of them had died in spite of this. That the water-loss took place in this way (through the stolons and into the stalks) and not through the periderm into the soil was shown by its typical occurrence in the older tubers with the thickest skins, by the localization of the softness to the heel-end, and also by the fact that all the tubers of a plant and all the plants were not equally affected. The soil appeared about equally dry throughout, and although some water can undoubtedly be lost through the periderm if the soil is dry enough, this cannot have been the main channel, or the majority of the tubers would have been more uniformly affected. That the injury was confined to so few plants is probably attributable to their having suffered most from the drought due to a combination of causes, including virus-infection leading to inability to control transpiration, proximity to a hard, trodden path, and other unexplained variations in soil moisture.

Although the softening was confined to certain plants, there was a gradual and imperceptible transition to plants with normally hard tubers,

and it was impossible to draw a line where the injury stopped. This was made clear after the crop was placed in a cool potato-store, in separate units, following careful hand-digging, for the tubers of a large proportion of the plants which appeared normal when dug softened to an unusual extent, and frequently sprouted, during October and November, while those of other plants did not do so. The relatively enormous loss in weight which the very soft tubers suffered is shown below, but the slight generalized loss was probably greater in the aggregate. It is concluded that this represents what occurred in the spraying experiment referred to later.

Absorption of water by soft tubers.—Immediately after digging, experiments were begun to determine the subsequent behaviour of the soft President tubers. The first preliminary test was started four days after digging, and was designed to determine to what extent these tubers were deficient in moisture and the rate at which water was taken up. Two soft tubers, as dug (No. 1 being very soft and shrivelled, No. 2 very soft but not shrivelled), and two normal tubers from the same plot were weighed and placed in moist soil (all in the same vessel) at room-temperature, and were afterwards removed and weighed at weekly intervals. The results are shown in Table 2 and Text-fig. 1.

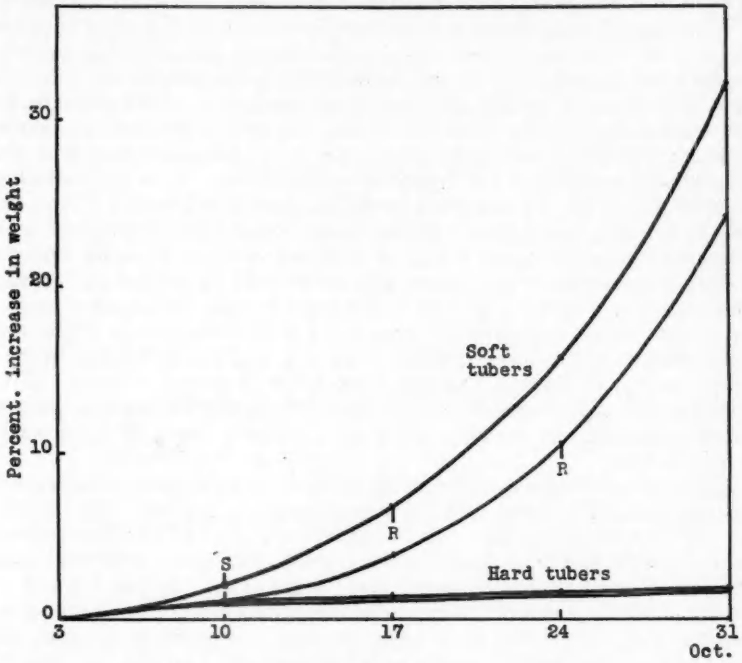
TABLE 2. *Water-absorption and Sprouting of Soft and Firm Tubers*

Tuber condition	*Date 1933*	*Weight in grammes*		*Increase per cent.*		*Remarks*
		Tuber 1	*Tuber 2*	*Tuber 1*	*Tuber 2*	
Soft	Oct. 3	56·7	50·2	100·0	100·0	
	10	57·9	50·7	102·1	101·0	Sprouts present
	17	60·7	52·1	107·1	103·8	Roots began
	24	65·7	55·6	115·9	110·8	Roots present
	31	74·9	62·4	132·1	124·3	Practically firm
Hard	Oct. 3	66·4	62·1	100·0	100·0	
	10	67·2	62·8	101·2	101·1	
	17	67·4	63·1	101·5	101·6	
	24	67·5	63·2	101·7	101·8	
	31	67·6	63·3	101·9	101·9	No sprouts or roots

The two soft tubers began to show sprouts from most of their eyes within a week (Oct. 10), and within three weeks these sprouts were up to 2·5 cm. long, and at that time well-developed roots were present. The soft tubers began to absorb water rapidly so soon as they were put in moist soil, and more rapidly still in the 2 or 3 weeks following the appearance of sprouts and, especially, of roots (marked by S and R in Text-fig. 1). The average increase in weight (which, neglecting respiration, practically represents the amount of water taken up) was 28·4 per cent. of the original weight within a period of 4 weeks (to Oct. 31). The normal tubers on the other hand did not show any sign of sprouting until Dec. 5, when the sprouts on the originally soft tubers were over 5 cm. long; they took up very little water (1·9 per cent.) during the 4 weeks, and, unlike the soft tubers, absorbed more than half of this in

the first week and from 70 to 76 per cent. in the first fortnight, after which the up-take was very slow. The appearance of these tubers on Dec. 5 is shown in Fig. 1, Plate 14.

The idea underlying the first experiment was that perhaps the soft tubers might absorb water in moist soil until an end-point was reached and they became hard again, thus giving a measure of the amount of water they had previously lost. Actually this never happens at ordinary



S = sprouts appeared. R = roots appeared.

FIG. 1. Water-absorption and sprouting of two soft and two hard President tubers in moist sand immediately after digging (1st experiment).

temperatures, for although water is absorbed slowly through the skin, most of it is taken up in the hastened sprouting that always ensues. Hence all that can be said is that some three weeks after sprouting and one to two after rooting, two very soft tubers had become almost normally hard again, and shrivelling (where present) had disappeared. At this point an average of 28·4 per cent. of water had been absorbed, but some of it had gone to produce sprouts and roots. This was confirmed in later experiments, for it was found that very soft tubers had to absorb between 30 and 40 per cent. of their original weight (during the process of which they sprouted) before becoming fully firm again.

Experiments conducted in 1935 showed that when just perceptibly soft freshly dug tubers were placed in moist sand at 0°–2° C. they

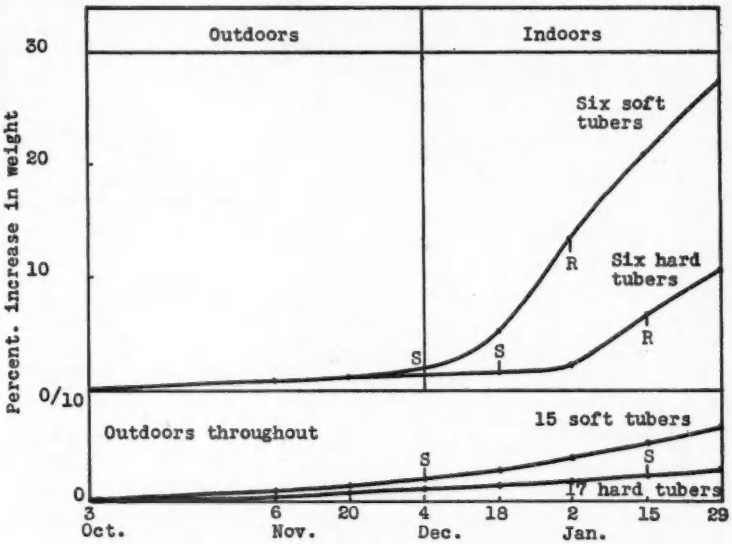
became firm again in 4 weeks (without sprouting) after absorbing 2·5–3 per cent. of their original weight of water. Hence a loss of water of this magnitude must make a noticeable change in tuber firmness. Under somewhat similar conditions, tubers designated 'softish' and 'soft' respectively, absorbed 6·2 and 12·4 per cent. of their original weights of water before becoming about normally firm again, while very soft tubers absorbed considerably more. These figures give a measure of the water-deficiency in soft tubers in the field.

The original experiment was repeated later in many forms in 1933 and 1935, with the same general result. The sooner the experiments were begun after digging, and the softer the tubers, the greater was the contrast both in water up-take and premature sprouting. Absorption by the soft tubers was always faster from the beginning, the rate increasing after sprouts and roots began to appear, and early sprouting occurred in direct proportion to the initial water-deficiency. It is not necessary to detail the work, but in one repetition, carried out in Dec. 1933 and Jan. 1934 in sand moistened with tap water, one very soft sprouted tuber increased in weight by as much as 31·6 per cent. in 6 weeks, and the average increase was 7·9 per cent., compared with maximum and average increases of 4·3 and 2·5 per cent. for hard tubers. In another similar contemporaneous experiment lasting for 4 weeks the average percentage increase in weight of the soft tubers was 26·5, and that of the hard tubers 6·7 per cent., and similar results were again obtained in 1935. In all cases the soft tubers sprouted in advance of the normal ones, so long as the temperature was suitable, the time-difference being about 2 weeks in mid-winter.

Effects of temperature.—The relationship of temperature to increase in tuber-weight, sprouting, and root-development, is illustrated in Text Fig. 2. In this experiment (*a*) 25 soft tubers, (*b*) 25 hard tubers from normal plants, and (*c*) 25 hard tubers from plants which produced some soft tubers, were placed in moist sand in the open. As lots (*b*) and (*c*) reacted similarly, the latter is excluded from the figure. After nine weeks progress was found too slow and one-third of each lot (1 pot) was brought into the laboratory (see upper part of Text-fig. 2), the remainder being left outside (lower part of Text-fig. 2). The weight-curves for soft and hard tubers generally follow the same courses at first as in Text-fig. 1, the former rising gradually and the latter running almost horizontally. But whereas in the first experiment the curve for the hard tubers appeared to diverge completely from the other, in the second the two curves eventually followed a similar course, but separated by an interval in time averaging 4 weeks. In other words, while early in the resting period only the soft tubers sprouted and took up any appreciable quantity of water, later on both soft and hard tubers did so, but at unequal rates, the soft tubers absorbing eventually 2–3 times as much water as the normal ones. The same events took place at a slower rate when tubers sprouted outside during the winter (Text-fig. 2, lower part). These tubers sprouted slowly and produced no roots during the experimental period.

There is abundant evidence that sprouting and water up-take are

accompanying and non-separable phenomena, for the weight jumps up when sprouts appear, and still more so when roots develop some 2, 4, 6, or more weeks later, depending on temperature, season, and tuber individuality. The remaining experiment, which relates to soft tubers only, makes this clear. It was carried out somewhat later (Nov. to Jan. 1933–4) and included 4 lots of 10 tubers each, which were put to sprout in moist sand at 20°, 15°, 10°, and 5° C., each lot including 1 tuber already sprouted and 9 unsprouted. Text-fig. 3 shows the behaviour



S = sprouts appeared on majority of plants.
R = roots appeared on majority of plants.

FIG. 2. Water-absorption and sprouting of soft and hard President tubers in moist sand in mid-winter.

of these at 20° and 15° C., and Text-fig. 4 at 10° and 5° C. The conclusion to be drawn from these Figures is that rapid absorption was a result of rooting, for the two events always followed each other. Sprouting had a less effect, as is shown by the contrast between the initially unsprouted tubers at 10° C. (Text-fig. 4), which sprouted slowly but formed no roots until the close of the experiment, and absorbed only 5·5 per cent. of water in consequence, and the sprouted tuber at this temperature, which rooted in a week and absorbed 47·7 per cent. Evidently 10° C. is a critical temperature which hindered the inception of sprouts but permitted rapid rooting of sprouts already present, and thereby led to an eleven-fold increase in length of the latter, compared with very little growth when roots were absent. The influence of sprouts in promoting absorption in the absence of roots is also shown (Text-fig. 4) by the greater increase in weight of a sprouted tuber at 5° C.

(9·6 per cent.) than of unsprouted ones at 10° C. (5·5 per cent.). The slow increase of unsprouted tubers at 5° C. (3·1 per cent.) was due to absorption through the skin, but they remained soft to the end.

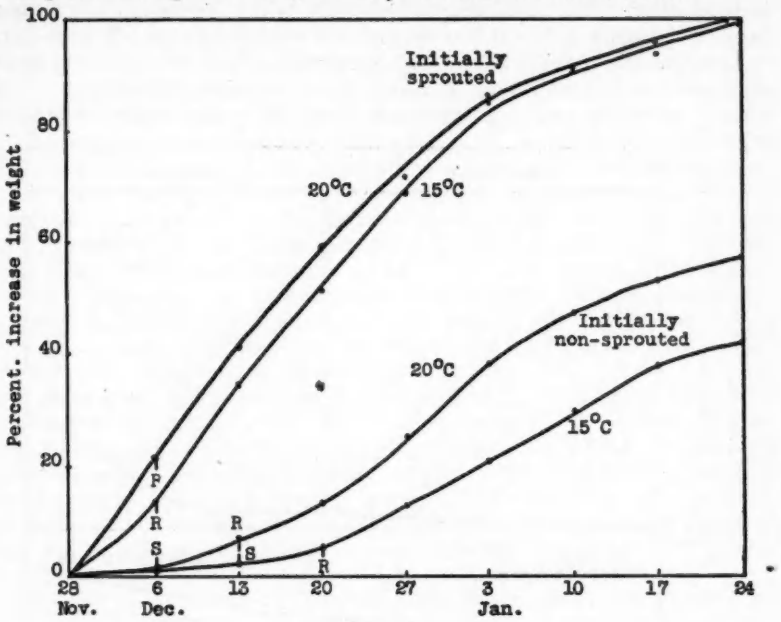


FIG. 3.

Effect on Yield of Potatoes Dug during Severe Drought

During the drought of 1933 an attempt was made to measure the rate of tuber-formation and to relate it to the development of blight (*Phytophthora infestans*) on the foliage. Three large uniform plots (variety Up-to-Date) were laid down of which one was not sprayed, one was sprayed three times with Burgundy mixture, and one eight times with a proprietary material which had a moderately good effect on blight but little checking effect on the foliage. A portion of each plot was dug at intervals of about 11 days from early August onwards, and the rate of crop increase thereby determined. The yields are shown in Text-fig. 5, and there is the usual evidence of variation due to soil factors, but apart from this it is clear that the three curves rise and fall together, evidently from the same cause. The two principal troughs followed the most serious dry spells and came at a time when the plants were suffering most severely from drought, viz. about Aug. 22 and Sept. 13. No obviously soft tubers were found, but there probably was sufficient generalized water-loss from the tubers to cause a measurable reduction in yield. In the sprouting experiments certain tubers, though not perceptibly soft to the touch, took up more water than usual, and others became soft and sprouted soon after digging. The crop in the spraying experiment was not stored.

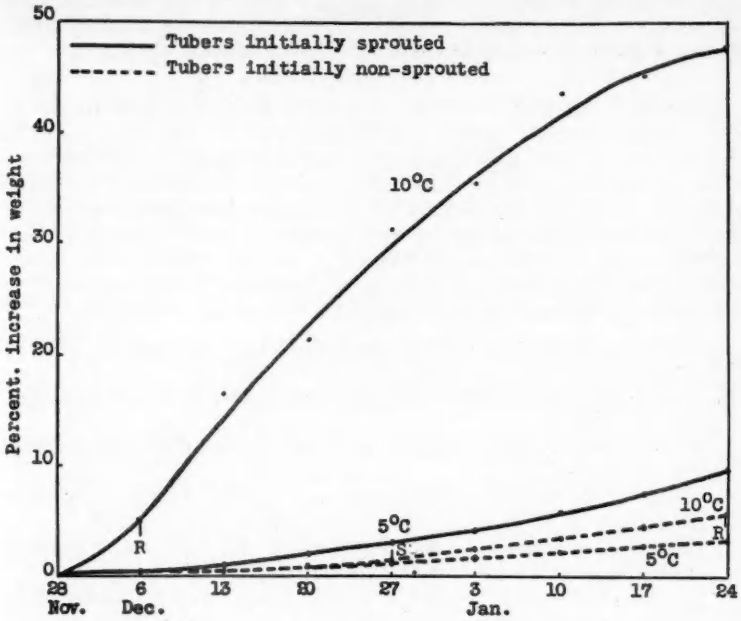

Tubers initially sprouted
Tubers initially non-sprouted
Percent. increase in weight
50
40
30
20
10
0
10°C
5°C
10°C
5°C
R
S
R
28 Nov.
6 Dec.
13
20
27
3 Jan.
10
17
24

FIG. 4.

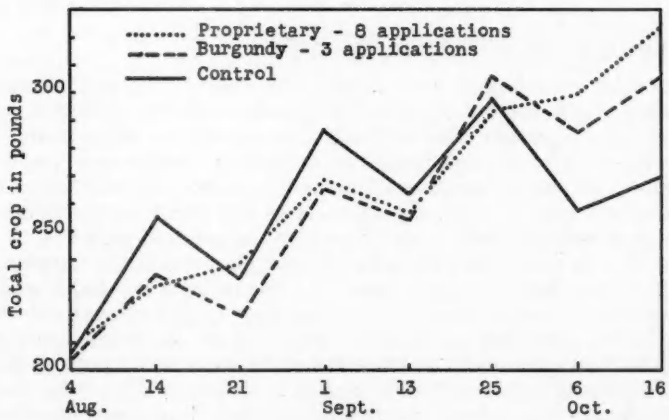

Proprietary - 8 applications
Burgundy - 3 applications
Control
Total crop in pounds
300
250
200
4 Aug.
14
21
1 Sept.
13
25
6 Oct.
16

FIG. 5.

Discussion

Various Forms of Drought-effects on Potato Tubers and their Interrelationships

It has long been known that irregularly shaped potato tubers and other forms of second growth are a feature of dry seasons, e.g. 1868, 1887, 1911, and 1921, and that they often keep badly and sprout abnormally in the following year. The recent dry years in Ireland (1933, 1934, 1935) have afforded opportunity for further study of this question, and it has been found that second growth, or more properly drought-effects, may take many forms. Some five of these have been recognized by previous workers, including Laplaud [2], Martinet [3], Shribaux [4], and McIntosh [5], but actually ten distinct types occur, as follows:

1. Cracking of the tubers as a result of resumed growth in thickness (p. 239).
2. Hollow heart, associated with large tubers and those showing cracking (p. 239).
3. Prolongation of the tuber axis at the rose-end, sometimes associated with glassy end and jelly-end rot (p. 239).
4. Gemmation, consisting of a knob-like outgrowth from an eye borne on a short thick neck which is never stolon-like (p. 240).
5. Chain-tuberization, the secondary tuber or tubers being separated from the primary by a stolon (p. 240).
6. Independent tuber formation taking place to an abnormal extent on new stolons arising from the stem, or on old stolons (p. 241).
7. Premature sprouting in the soil or immediately afterwards, the outgrowths from the tubers becoming stems, which may come above ground, instead of stolons (p. 241).
8. Stem-end wilt, sometimes associated with stem-end rot, and leading to premature sprouting (p. 243).
9. Glassy end and jelly-end rot, often associated with prolongation (p. 243).
10. Drought and heat necrosis (p. 244).

The type of second growth depends on the variety and maturity of the tuber when the rains come [2, 6]. Most of the types are due to resumption of growth after a check, this taking the form either of an increase in size of the original tuber (cracking, hollow heart, and prolongation), or an anticipation of normal sprouting (chain-tuberization and premature sprouting). In other cases the effect is due to drought alone, as in stem-end wilt, there being no true second growth.

It is difficult to separate the effect of drought from that of temperature, since the two generally occur together. The maximum shade temperature recorded for short periods in Ireland (27° C.) is too low to do appreciable harm, and tip-burn is absent, but injury and even death from drought are known. On the other hand, temperature is considered the more important factor in America, and can cause harm in the absence of drought, the tubers being more sensitive than the foliage, but drought without heat is considered harmless [7, 8]. Some American varieties,

e.g. Rural New Yorker, are notably resistant to hot, dry weather, and in NW. Europe potatoes are apparently very susceptible on account of their hygrophytic habit and early growth at low temperature and low insolation.

1. *Cracking* (cf. Fig. 3, Plate 14) is often associated with hollow heart, and certain varieties are susceptible, including Ally, Scottish Chief, Majestic, Irish Queen, Great Scot, Roode Star [5, 9, 10]; Quitte, Ostragis, Goldstärke, Betula, Columba, Feldglück, Feldspende, Goldgelbe in Europe (aut. Volkart), and Rural New Yorker No. 2 under irrigation in America [11]. The cracks are due to resumed growth following a check caused by drought, and they usually heal over. Absence of boron aggravates the injury [12], as do forms of the virus diseases curly dwarf, streak, and spindle tuber [13, 14, 15, 16, 17], as well as rugose mosaic.

Cracking sometimes develops also in the act of digging, or afterwards, in Bliss Triumph [18, 19] and Red King [20], and is attributed to over-turgidity, as when frost kills the foliage but allows root-action to continue. The condition has been reproduced experimentally in the present work by storing freshly dug tubers in moist sand at 0°–2° C. for 6 weeks (Fig. 9, Plate 15), when cracking began, appearing first in a tuber dropped 2½ ft. on to a wooden floor, and later on spontaneously in others. At this stage the tubers had absorbed 4·2–7 per cent. of their weight of water. Macmillan [18] found that when naturally over-turgid tubers lost 6 per cent. in weight they ceased to crack.

2. *Hollow heart* is a disease mainly of large tubers, the optimum soil temperature for which is 18° C. approx. [21], and it predominates therefore in moderately warm potato countries, such as Germany, the northern U.S.A. and Canada, where as much as one-eighth of the crop may be affected. The starch disappears from the central pith, which becomes watery, as in glassy end, and then breaks down, resulting in a lens-shaped or irregular hollow, surrounded by a layer of dead cells, and sometimes a cork layer, which rarely communicates with the exterior [22]. The attack is most severe under irregular irrigation, but it may be common also in dry-land culture when rain follows drought in August or September [11, 23]. Other conditions favouring the attack are small sets, wide spacing, misses, few stalks and tubers per plant, excessive potash which delays maturity, and excessive nitrogen [11, 23, 24, 22; see 25, 24, 26 on the influence of manures on tuber-shape and size]. The attack is frequently associated with cracking and the virus disease, spindle tuber [27, 15]. The following varieties are susceptible: Arran Consul, Irish Queen, Great Scot, Arran Banner, Roode Star, Rural New Yorker No. 2, Allerfrüheste Gelbe [28, 10, 11].

3. *Prolongation* consists of the protrusion of the whole rose-end of a tuber following a stoppage of growth, which results in a constriction or waist (Fig. 6, Plate 16). The new growth is smooth-skinned, and may be nodular at first but generally becomes a symmetrical extension of the original tuber in the direction of its long axis (Figs. 2, 3, Plate14). Long-tubered varieties are principally affected, including British Queen, King George, Puritan, Catriona, Golden Wonder, and Early Rose [5, 2]. In

the dry seasons of 1934 and 1935 in Ireland it was observed in Arran Cairn (the most susceptible British variety) and Arran Pilot, in association with glassiness, jelly-end rot, and other drought-effects.

The relationship of weather to prolongation is shown by experiments in the hot climate of Ohio on straw-mulching, which prevented second growth in the soil (mainly prolongation), as well as stem-end softening and premature sprouting in storage [29, 30, 31]. The association of softening and premature sprouting is to be observed. The good effects of the mulch are attributed to water-conservation and to reduced soil temperature, leading to more uniform growth. It is to be noticed that, apart from second growth, high soil temperature and abundant moisture lead to the production of long tubers [21, 16], as do spindle tuber and some other virus diseases [27, 15, 32], and certain manures [26, 25].

The new growth is occasionally larger than the old (Fig. 7, Plate 15), resulting in 'bottle-necks' [16]. These cases frequently develop into glassy end and jelly-end rot (q.v.), owing to the transport of materials from the original growth into the new, with the result that the former decays, but in other cases the leaves provide the new materials [33].

4. *Gemmation*, the characteristic second growth of the best potato climates, such as Ireland, and generally the commonest drought-effect [2, 3, 4], consists of the protrusion of a single eye into a knob-like growth situated in the axil of the rudimentary leaf-scar or 'eye-brow', various stages of which are shown in Fig. 4, Plate 15. The gemmae have smooth skins and many eyes and green rapidly on exposure. They are produced during autumn rains following dry summers, or as a result of irregular irrigation, and particularly among susceptible varieties. The disease has been reproduced experimentally by irregular watering and may be aggravated by certain fertilizers, and sometimes also by spraying, which prolongs the life of the foliage [11, 34, 35]. The susceptible varieties include Buchan Beauty, May Queen, Kerr's Pink, British Queen, King George in Ireland and Great Britian; Saucisse, Géante Bleu, Deodara, Arran Victory in Europe [2, 3]; and Burbank, Early Ohio, and Triumph in America [36, 30, 11]. In bad attacks half the crop may consist of second-growth tubers [2, 3].

As in other cases, the materials which make up the gemmae are sometimes derived from the foliage following resumed assimilation and transport after a drought, and sometimes from the primary tubers, in which case the latter may become so light as to be worthless, or they may subsequently produce spindling sprouts and make poor seed-potatoes [3, 2, 6, 37]. The greater part of the minerals is apparently transported from the primary tubers to the secondary in such cases, unlike what happens in normal sprouting [3, 38]. Gemmation is not confined to tubers attached to a living plant, for it can take place after the parent plant dies [33], and in cases of deranged sprouting in storage or after planting [39, 40, 41, 42], which are generally due to a delayed effect of drought.

5. *Chain-tuberization.* Little is known of this condition (Fig. 5, Plate 15) which is regarded as a serious fault. It consists of the production from an eye of one or occasionally more stolons bearing a secondary

tuber, which may produce a further stolon and tertiary tuber, and so on in bad cases more or less indefinitely. The new tubers are usually, but not invariably, small and immature. Irish Chieftain, Northern Star, Kerr's Pink, and Arran Chief are susceptible [9]. Prolongation, gemmation, and chain-tuberization form a series probably indicating a progressive decrease in the capacity for growth of the primary tuber, for in the first the whole rose-end proliferates, in the second the whole of an eye, and in the third a single bud from an eye. A pronounced form of the disease occurs in the virus disease, witches' broom [43, 44].

6. *Independent tuber-formation*, consisting of the production of small new tubers either on fresh stolons or on the old ones, has been noticed particularly in France during autumn rains following drought [4]. The length, number, and branching of stolons increase under conditions favourable to vegetative growth (high temperature, long days, and abundant nitrogen), but under the opposite conditions stolon-growth ceases when the first tubers are set [24], a tendency which is accentuated by lack of potash [12]. When rain follows drought, a further growth by long thick stolons may result [45], and high soil temperature (27°–30° C.) has also been found experimentally to lead to the production of swollen stolons and underground stems [21], a condition which is sometimes found in the field [46].

7. *Premature sprouting in the soil or afterwards.* Sprouting in the soil during summer or autumn, resulting in the production of erect shoots which may come above ground and even produce a second crop of tubers, is very rare in Ireland or Scotland, but was observed in the dry years 1933, 1934, and 1935 in Sharpe's Express, British Queen (twice), Ninetyfold, and an unnamed seedling. The condition is said to be not uncommon in SE. England, in association with tuber-shrivelling, especially in Arran Victory, and also in King Edward, Ballydoon, and Sharpe's Express. It has also been reported in Germany [37], and Connecticut [47], but is more common in warmer countries, such as Jamaica (oral information from Dr. F. E. V. Smith), and California, where Up-to-Date (referred to as British Queen) is susceptible [36, 48]. Blighted tubers are particularly prone to premature sprouting, as are those affected with the witches' broom or wilding virosis [43, 44, 44A].

It is remarkable how little is known of this very pronounced form of premature sprouting. It is generally held, on the authority of Klebs [49, p. 137], that tuber-dormancy does not set in until the last stages of growth, and this is held to account for the sprouting of half-grown tubers. The experimental basis [50, 49, 51] is very slight and rests almost entirely on plants grown in pots under glass, which are very prone to second growth and other drought-effects. The present author has failed to confirm Herfel's work [51] in this connexion. Klebs' conclusion is also opposed to experience, for immature tubers do not have a shorter resting-period than mature ones [37, 48].

It has been shown in the experimental portion of the present paper that premature sprouting is a consequence of water-loss from the tubers as a result of drought. The present problem therefore is to determine why the new growth takes the form of aerial shoots rather than stolons.

The destiny of sprouts emerging from tubers is alterable by external conditions, e.g. long days, high temperature, and abundant moisture cause stolons to grow upwards and become aerial shoots [52, 24, 48]. A short day following a long one has apparently the same effect [53], and a light dressing of naphthalene has been found at Glasnevin to cause the stolons to grow up to the light also.

It is probable that the presence of roots is necessary before aerial shoots can appear, for without roots the elongation of sprouts in light is impossible [54] and their growth in the soil is limited [40, 41], as already shown in the experimental portion of this paper, apparently because the new growth is dependent on the roots for its mineral supply [38]. The soil conditions which lead to copious root-production are probably similar to those governing the rooting of cuttings [49, 55], and consist principally of a moist soil which injects the intercellular spaces of the young developing shoot and leads to reactivation of the cambium and consequent root-production, and a high temperature [6, 48]. Etiolation or the prior presence of leaves is not a factor [55], because rooting of the sprouts begins in the absence of both.

Premature sprouting, in storage and consequent faulty germination after planting are delayed developments of the same phenomenon and arise from the same causes, seeing that they commonly follow drought years [46, 41, 56]. Furthermore, in mulching experiments, a straw cover was found to prevent not only prolongation but a tendency of the tubers to wilt at the stem-end in store and to sprout prematurely [31].

The present experimental work provides, so far as is known, the first experimental connexion between water-loss from the developing tubers and loss of dormancy. The explanation is in harmony with practical experience, for northern seed-potatoes are more dormant than southern ones, and those grown on sand are generally earlier than those grown on clay or bog. In warmer climates tubers from the summer crop have a 1–6 weeks' shorter rest-period than those maturing in autumn [57]. Under still hotter conditions, as in tropical Africa and the southern United States [29], dormancy is completely lost and the tubers vegetate at once when returned to the soil after digging the previous crop.

8. *Stem-end wilt and water-loss.* Visible wilting of the tubers is extremely rare in Ireland and has been observed only four times in the dry years 1933 to 1935, in President, Arran Pilot, and British Queen. It has not been reported from Scotland, but is apparently commoner in southern England. The first known record is by Appel [46], following the great drought of 1911, and similar records were made in 1921 [58, 59]. The condition is best known in the western United States, where tubers at harvest may show a withering of the stem-end 'as though part of the water had been withdrawn from that portion', sometimes accompanied by jelly-end rot [60]. The injury is attributed to drought and excessive transpiration, as a result of which the leaves draw on the tubers to eke out the water-supply, a probable consequence being the sprouting of half-grown tubers and other forms of second growth [36, 48]. In other cases, in the present work as well as elsewhere [31], tubers grown under hot and dry conditions may show no perceptible sign of softening

at digging, but they wilt rapidly in storage and sprout prematurely. It is practically certain that these also must have suffered a loss of water during the growing-period, but carbohydrates and nitrogen may also decline under hot, dry conditions [24, 3].

The changes which result in wilting, half-grown tubers have been found in the present work to include partial or complete disappearance of starch from the heel-end and an increase in the amount of reducing sugar (see [61] for method of estimation), an occurrence which is paralleled by wilting leaves [62]. There are other instances also in which water-loss leads to premature or forced growth of woody or bulbous plants [63], but the mechanism of the connexion is not entirely clear.

It is generally agreed that experimental shortening of the rest-period of potato tubers is correlated with an increase in oxygen-absorption and sugar-content. Thus the following treatments promote early sprouting, and all of them are accompanied by a rise in sugar-content and respiration: lengthened storage at or near 0° C. and subsequently at a higher temperature, peeling and wounding, treatment with various chemicals, and heating in water or in air. Loss of water from tubers stored in a room is also said to lead to heightened respiration at first, which drops on further water-loss and again rises when the shrunken tubers are put in water [64]. It is evident that water-loss from the growing tuber must operate along similar lines.

When unsprouted soft tubers are placed in moist soil, they begin at once to absorb water slowly but do so much more rapidly when sprouts and roots appear. This is clear from Text Figs. 2 and 4, and is opposed to the conclusion that most of the water is absorbed through the lenticels [51]. The swelling of soft tubers to more than their original size is well known [51, 65, 66], and is in keeping with the fact that the plane surface of cut sets becomes convex after planting.

9. *Glassy end and jelly-end rot* is a rarity in Ireland and has been found only in Arran Cairn and Arran Pilot, which are particularly susceptible, as is Golden Wonder in Scotland and Burbank in the United States. All these varieties have long tubers. The disease has been most fully described in Australia [67], where it is attributed to drought which injures the leaves to such an extent that they are not able to supply all the carbohydrate needed for new growth (i.e. second growth) when rain follows. Tuber-composition is affected by the disappearance of starch and an increase in reducing sugar in the glassy portion; but the Australian work makes no mention of water-loss. There may be no external symptoms, or the tubers may show stem-end rot.

Observations in Ireland show that glassy end follows drought and is associated with some or all of the following: second growth, stem-end wilting, and premature sprouting, and is usually followed by jelly-end rot (Fig. 2, Plate 14). The stem end shows a progressive soft rot, in advance of which the flesh is yellow and glassy and devoid of starch. The rot eats away a large part of the original tuber and then stops and is sloughed off, as though cut off by a knife (Fig. 3, Plate 14). No parasite capable of rotting normal tubers is present. In one case the specific gravity of the glassy portion of a tuber was 1·047, of the middle portion 1·100, and

of the terminal portion 1·134. The sequence of events in these cases is believed to be: water-loss due to drought, second growth mainly at the expense of the primary tuber, and rot of the evacuated stem-end. Apart from water-loss, however, tubers may lose carbohydrates and nitrogen under certain very hot conditions, and may even be completely re-absorbed [24].

The extensive literature connecting species of *Fusarium* with the American jelly-end rot (Fig. 7, Plate 15) cannot be reviewed. The same association has been noted in Ireland in the last three years and a species of *Fusarium* which is at present under study, amongst other fungi, has been isolated, but all failed completely to produce rot in normal tubers.

10. *Drought and heat necrosis.* This disease occurs under very hot conditions and is marked by the death of the vascular ring and surrounding parenchyma, which turn golden yellow and later brown. It is most marked in the outer phloem and cortex, especially at the rose- and heel-ends, which distinguishes it from net necrosis which also occurs in the pith. In another form of the disease, groups of yellow or brown dead cells, varying from specks up to one-half inch in diameter, develop in any part of the flesh, sometimes in storage [34]. The diseases occur in hot, dry, light soils, particularly when the plants are dying from drought and the crop is left undug, but they have not been reproduced experimentally and their relationship to other forms of tuber-necrosis due to overheating [68], calcium deficiency [12], and viruses [69, 70, 1], remains to be determined.

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Summary

After the dry summer of 1933 a few President tubers were found at digging time to be soft, due to loss of water. These tubers sprouted at once in October when placed in moist sand, but hard tubers from the same plot did not do so.

Many tubers from this plot, which were not noticeably soft when dug, shrivelled and sprouted prematurely during storage in autumn.

The absorption of water by soft tubers began at all temperatures from 5°–20° C. as soon as they were placed in moist sand, and continued at a slow rate until, at favourable temperatures, sprouts and roots appeared. Sprouting increased the rate greatly, and rooting still more so.

As a consequence the tubers became firm again, having absorbed about 30 per cent. or more of their original weight of water. Tubers at low temperatures which did not sprout were still soft after 8 weeks in moist sand, showing that most of the water is absorbed through the sprouts and roots.

Evidence is presented that the yield of crops dug during severe drought may be reduced by water-loss from the tubers.

Various effects of drought on potato tubers are discussed and 10 types are defined and described. These are cracking, hollow heart, prolongation, gemmation, chain-tuberization, independent tuber-formation, premature sprouting, stem-end wilt, glassy end, and drought and heat necrosis.

The occurrence of these various types in different countries and on different varieties is described, and the conditions favouring them are discussed. It is shown that a number occur in association, such as cracking and hollow heart, glassiness, jelly-end rot and prolongation, softening and premature sprouting.

The production of leafy shoots from half-grown tubers is connected with free formation of roots in a moist soil, and the loss of dormancy by soft tubers with starch hydrolysis following partial desiccation.

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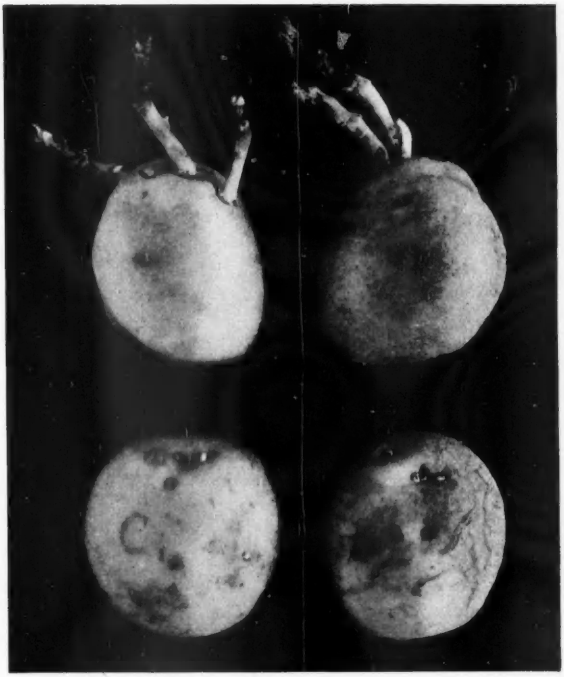

FIG. 1

FIG. 2

FIG. 3

(1) *Above.* Two soft tubers which sprouted at once after digging, showing complete absence of dormancy. *Below.* Two normal tubers from same plot. See Expt. 1 (Photo. 5.12.33). (2) Jelly-end rot (*below*) and prolongation in Arran Cairn. Note waist, smoother skin of new growth, and blackening at tip due to rubbing. (3) Same, showing disappearance of large part of original tuber, nodular second growth showing superficial injury and cracking (Photo. Feb. 1935).

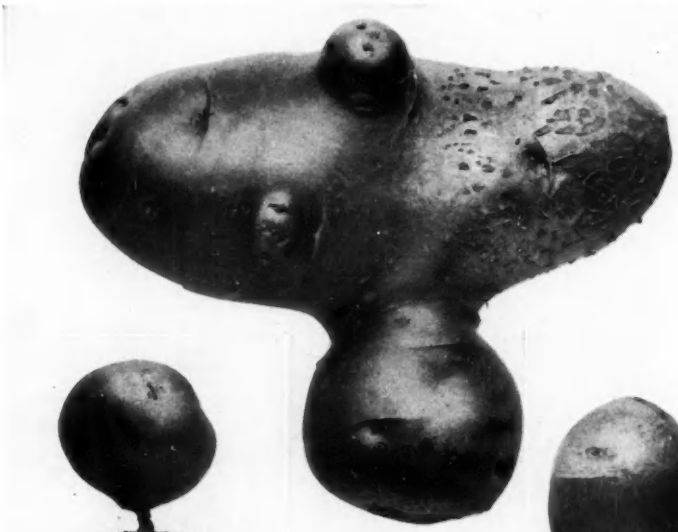

FIG. 4

FIG. 5

FIG. 6

FIG. 7

FIG. 8

FIG. 9

(4) Second growth by gemmation in Majestic showing various stages of development. (5) Chain-tuberization in President. (6) Prolongation in President. (7) Extreme case of prolongation in Arran Victory, the small projection representing the original tuber. (8) Jelly-end rot in Burbank. (9) Cracking experimentally produced in dormant tuber in moist sand at 0°–2° C.

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SOME ASPECTS OF TOBACCO CULTURE IN CENTRAL AFRICA

C. W. B. ARNOLD

TOBACCO is a weed only in the sense that it can be grown anywhere in the world. The production of tobacco with a value in the world's markets, however, has regional limits owing to the profound effect on the crop of such factors as soil, rainfall, sunshine, and humidity. Even with suitable soil and climate it may still fail commercially owing to the attacks of soil pests: nematodes, cutworms, stem-borers, leaf-eating caterpillars, beetles, grasshoppers, aphids. It is susceptible to mosaic and other virus diseases as well as to leaf-spotting fungi and bacteria, which reduce the yield and quality of the product.

On the economic side, the cost of agricultural labour is a very important factor in tobacco culture, as each leaf has to be handled many times from when it is taken from the plant until it is packed in bale or hogshead for shipment to the manufacturer. Only cheap agricultural labour can produce tobacco at a competitive price.

Varieties.—Few agricultural crops show such specialization as is found with tobacco; new varieties are being bred and improvements are continually being made in the older strains to make them more suitable for the production of particular types of cured leaf. The large distinction among the varieties is based on their suitability for curing by one or other of the standard methods and yield of leaf for a specific purpose: (1) fire-cured; (2) sun-cured; (3) air-cured—Burley; (4) air-cured—cigar-leaf; (5) flue-cured—pipe-grades; (6) flue-cured—cigarette-leaf.

Numerous varieties have been developed which are specially adapted for yielding a high-quality product of one or other of these main classes. There is no 'utility variety' which, by merely changing the method of curing, could give a cigar-leaf, pipe-leaf, or cigarette-leaf of high quality.

Presuming now that flue-cured pipe tobacco is aimed at, the choice of variety must still be made, and experimental work becomes all important. Experience shows that a successful variety in one region may fail in another owing to obscure differences of soil or climate. The process of improvement of varieties has doubtless introduced weakness or sensitiveness, and thereby limited the region in which a particular variety can be grown successfully. Actual trials only will decide the most profitable one for a given area, and every plantation should have trial plots on which selections from the farm or another variety can be compared with the main crop.

Variety trials.—Exact experimental work with tobacco presents many difficulties. The value of a field of tobacco is not seed-weight, green-weight, or even cured-weight, but sold weight of cured leaf per acre. Nevertheless, in any variety trial, the appearance of the plants in the field, their vigour as judged by the number of leaves they will carry, resistance to disease, ability to withstand excessive rain or drought, and rate of ripening, should be observed and recorded. No variety can be a commercial

success which fails the test of its field characters. Errors are more likely to occur during the operations of harvesting, curing, bulking, and grading. Close supervision is essential from the time the ripe leaf is harvested until it is sold, and few planters are able to carry this through and furnish reliable reports. This is the work for the experiment station.

Variety trials on most farms might well be limited to obtaining field observations on one or two varieties, using plots of ¼-acre each. A single variety could be carried through the curing and grading on the farm, provided a minimum of 5 acres is planted. This area would enable one barn to be filled completely with the variety under trial.

If smaller plots were used, the amount of leaf harvested at one picking would be too small to fill a barn, and attempts to cure mixed barns, i.e. those filled with leaves of two different varieties, invariably fail, as no two varieties cure exactly alike. One has to be sacrificed in favour of the other, and the smaller lots from the variety under test always suffer, with the result that it is condemned as showing 'bad curing qualities'. Even if this difficulty is avoided, the amounts of leaf produced are too small to bulk down separately, and become lost or mislaid. Should they be duly graded the quantities of the grades will be small and difficult to value.

A variety cannot be condemned or approved outright after one season's trial. All the circumstances of the season must be given due consideration, and a promising variety should be tried out for three successive seasons to appreciate its value under varying seasonal conditions. It is the value per acre in bad seasons that is the critical test, as a mediocre variety will yield well under good conditions.

Tobacco soils.—A soil can only be considered as suitable for the culture of tobacco on a commercial scale if it yields a product which is acceptable to the smoking public. As with all luxury products, the taste of the consumer is paramount. Experience shows that rich soils, i.e. those rich in organic matter and nitrogen, are not as a rule 'tobacco soils', for although growth will be vigorous and yields may be heavy, the cured leaf is usually thin and trashy, and tobacco manufactured from it smokes rank and objectionable.

Each of the types mentioned above has its appropriate soil, and the ideal for producing bright cigarette-leaf is a light sand, poor in humus and nitrogen, rich in phosphoric acid and potash. The soil should be as light as possible in colour and with only meagre iron-content. Such an ideal soil is virtually non-existent, for with this richness in mineral constituents it would naturally have encouraged the growth of vegetation during the ages and have been converted into a rich soil, i.e. rich in organic matter and nitrogen from accumulated plant-residues.

The soils which approximate to the ideal evidently suffer from some disability, but deficiencies can always be remedied by the addition of appropriate amounts of plant-foods, whilst excesses cannot easily be got rid of. They must be poor in organic matter and nitrogen, and, indeed, some are remarkably poor and are little more than light-coloured sands, capable of holding a stick upright but with little natural fertility.

If the colour of the cured leaf is of less importance, as in flue-cured

pipe-grades, air-cured leaf, dark-fired leaf, larger amounts of nitrogen and organic matter are permissible, and the heavier grades may be produced on relatively fertile soils.

The physical character of the soils is rather less restricted. Their essential feature is that they must be of open texture and naturally free-draining. The tobacco plant will not tolerate a water-logged soil but will promptly die, possibly from deficiency of aeration, and certainly as a result of injury from fungi or bacteria that are encouraged by the water-logged condition. The plants succumb quickly and root-disease cannot always be proved. All forms of subsoil pan are inimical.

In cases where good tobacco has been seen on loams, there was always a natural looseness of the soil *in situ*. Virgin land almost invariably gives good tobacco for a year owing to its excellent texture, due to the presence of large quantities of undecomposed plant-residues, not yet humus. When these have been converted to humus, the amounts of the ultimate soil particles, sand, silt, clay, humus, decide the soil texture. One finds it almost essential to judge the soil *in situ* in order to decide its suitability for tobacco.

The tobacco plant.—As grown for commercial purposes the tobacco plant has an unnatural life. It is sown in a seed-bed of rich or heavily manured soil which has been sterilized by heat and is carefully shaded and watered. After 6 to 8 weeks it is planted out in a field which has been carefully prepared and manured. For 2 or 3 weeks growth is slow, but later on it becomes very rapid, and the flower-bud appears 7 or 8 weeks after transplanting. At this stage, the treatment of the plant depends on the type of tobacco which is to be produced. With bright flue-cured varieties, the flower-head is allowed to expand about half-way, and at this stage the natural development of the plant ceases as the flower-head and certain leaves at the top and bottom are removed. In its endeavour to produce seed it pushes out suckers in the axils of the leaves. These are removed, and a second crop of suckers appears, which receives the same treatment. This induces an unnatural expansion and thickening in the remaining leaves, which gradually become paler in colour and brittle. When this condition is sufficiently developed, they are harvested one or two at a time, starting with the lowest leaf, tied to bamboos, and carried to the barn for curing.

One can regard the life of the tobacco plant as comprising the following stages:

Stage 1. The nursery period lasting 6 to 8 weeks and terminating with transplanting.

Stage 2. The period of slow growth following transplanting lasting 2 or 3 weeks. The young plants are recovering from the shock and are becoming accustomed to full sunlight, heat, a change of soil, and generally the hardships of field life.

Stage 3. The period of vigorous growth lasting 4 to 5 weeks and closing with the topping.

Stage 4. The ripening period lasting 4 to 6 weeks.

In the first three stages there is a considerable intake of plant-foods, and elaboration takes place in a natural manner.

The ripening period is abnormal, as seed-production is frustrated and

a sort of fattening process is induced. All plant-food taken in during this period is forced into the limited number of leaves, and any considerable intake of nitrogen is attended by disastrous results. Its obvious effect is to cause the rich green colour to stay obstinately in the leaf, or, as the planter describes it, the leaf 'refuses to ripen'. If such unripe leaf were harvested it would cure badly and produce either muddy, blotchy colours, or dry out green and yield a low grade or even an unsaleable product. The ideal condition would be for the intake of nitrogen to cease with topping. The tobacco plant, however, is a gross feeder, and if nitrogenous plant-food is available it will continue to absorb it throughout its life. Unfavourable weather conditions at this stage result in outbreaks of leaf-diseases, which are more severe on rich land and on land which has received heavy dressings of nitrogenous manure.

When this point is grasped, the planter will understand the reason for some of his failures. It will explain why a rich soil is unsuitable for bright tobacco, why the composition of the manurial mixture, and especially the forms of nitrogen in it, are important, and the cause of the condition called 'second growth'. Rainfall is beyond control, but it is for the planter to exercise great care in the selection of his tobacco fields, in manuring and cultivation.

Manuring

The whole subject cannot be dealt with here. The principles, however, can be inferred from the foregoing remarks on the soil and the plant. Different manuring-systems must be adopted according to the type of tobacco under cultivation and according to the soil.

Some of the soils used for the production of dark-fired tobacco in the Lilongwe district of Nyasaland have produced crops of excellent tobacco for a few seasons without any fertilizer. Climatic conditions there usually favour the cessation of nitrogen-absorption after topping, with the result that perfect ripening takes place. At the first sign of exhaustion, the land is abandoned; soil amelioration and manuring are left for a later generation.

The soils used for producing heavy, flue-cured tobacco (pipe-grades) in Nyasaland are often rich in nitrogen and organic matter and have a fair mineral content. Newly opened land, where the nitrogen is still largely locked up in plant-residues, gives crops of good quality, and a small application of quick-acting nitrogen often improves the yield without depressing the quality. The difficulty on the older soils is to avoid big, leafy growth, which ripens slowly and colours very slowly in the barn, producing tobacco which is dark in colour and of inferior texture. No nitrogen is applied in the second or third year, but double superphosphate and potassic superphosphate are used according to the known deficiencies of the soil. It seems doubtful whether this manuring is really effective after the third season, and a change of crop is necessary.

Bright tobacco soils are more common in Southern Rhodesia. They have the desirable low organic matter and nitrogen, and are usually deficient in one or more minerals. They would be classed as sands or light sandy loams. Without additional nitrogen, growth is poor and

small. Manuring is essential and in most cases complete fertilizers are required. In this country of large farms, the custom appears to be to abandon fields after two crops have been taken, and few planters have seriously tackled the problem of how to maintain or regenerate the fertility of their old fields.

No standard manurial formulae can be laid down for flue-cured tobacco in Central Africa similar to the 8–3–3 or 8–3–5 (P_2O_5–NH_3–K_2O) which are in general use in the United States. The soils are too varied in composition, and whilst some require little nitrogen, others require 25 to 30 lb. per acre. Artificial manures are costly, and no farmer can afford to put out manure which yields no return. The maximum effective applications of phosphoric acid and potash are about 30 lb. per acre, larger amounts showing no additional benefit.

The form of nitrogen in a manurial formula is of the greatest importance, and must be considered in conjunction with the soil nitrogen, the rainfall of the district of application, and the nature of the preceding crop. Organic nitrogen, such as is derived from fish, blood, meat-meal, and oil-seed residues, cannot be leached out by rain, and yields a continuous supply of nitrogen throughout the season. Soil nitrogen derived from plant-residues and green manures is of similar availability. These forms are beneficial in moderate amount and especially in wet seasons. When present in excess they are injurious by promoting growth when it is desired that the tobacco should ripen, i.e. after topping. Inorganic nitrogen derived from nitrates is entirely available from the time of application. The soil cannot hold it and any that is not taken up by the plant is leached out by rain. Should continuous rain be experienced shortly after application, much of the nitrate will have gone before the plants can take it up. Nitrates can be regarded as very safe in the respect that they are likely to be exhausted by the end of the third stage. Inorganic nitrogen in the form of ammonia (sulphate of ammonia, diammonium phosphate) is retained by soil to a great extent and cannot easily be leached out. Under the influence of soil bacteria it is progressively changed into nitrate, which more or less suits the demands of the growing plants. Ammonia is not so safe as nitrate, as climatic conditions may occur which delay its action unduly.

The proportions of these forms of nitrogen should suit the requirements of the plant in the average season, and they must be determined by careful trials over a succession of seasons. If they were ideal in a dry season, they would be quite unsuitable in a wet year. The proportions recommended by a Conference of Tobacco Experts in the United States are of great interest in showing the adjustment of components of various degrees of availability:

'*Ammonia.*—One-half of the ammonia should be derived from high-grade organic materials of plant or animal origin, such as cottonseed meal, fish-scrap, and high-grade tankage. At least one-fourth of the total ammonia is to be supplied by nitrate of soda. The remainder should be derived from such materials as urea and/or standard inorganic sources of nitrogen. For the heavy Cecil soils of Virginia three-fourths of the ammonia may be derived from the above-designated mineral sources and one-fourth from the organic sources of plant or animal origin.'

Note the recommendation that the slow-acting organic nitrogen should be reduced for tobacco growing on richer soils.

The phosphoric acid in the mixture should be derived for preference from ordinary or low-grade superphosphate. The potash should consist of sulphate and muriate in equal proportions.

Method of application.—One has listened to much argument on this topic and wondered how little the feeding of the plant has been considered even by those who set out half a million or more tobacco plants every season. If three well-grown plants were dug out after harvest in a dry season, and also after a wet season, and examined, there could be little difference of opinion in the matter. The thick cluster of feeding rootlets will be close to the surface in the wet season and somewhat deeper in the dry season. The spread of the roots indicates the feeding-range. Fertilizer should be so distributed that, whether the season is dry or wet, some of it will be accessible. Occasionally when pulling out a stalk after harvest, one or two grey cartridge-like blocks of fertilizer have been dislodged, reminding one of the buried talents which yielded no interest. The method of application was obviously wrong.

Tobacco fertilizer should be well mixed with the soil and never placed in a single spot. It should be covered to prevent it being carried away by heavy showers. Phosphoric acid and potash are very soon fixed by the soil and tend to remain where they have been placed, i.e. they have little or no mobility. Nitrogen in the form of nitrate is very mobile and tends on the whole to move downwards.

Side dressings.—The advisability of applying additional fertilizers after the plants have been established for a week or more has often been raised. Such dressings are variously described as side-, top-, or after-dressings. Their use will depend on local circumstances, the soil, and on the loss which has meantime occurred in consequence of leaching rains. When transplanted, the leaves are very small and quite inadequate to protect the surrounding ground from severe washing. The proportion of nitrogen lost when, say, 10 in. of rain have fallen will naturally depend on the composition of the fertilizer and on the soil-type, and careful consideration should always be given before applying after-dressings. The planter must realize that he is speculating on the weather of the remainder of the season. A very rainy period is often succeeded by two or three weeks of drought, and any fertilizer supplied at the beginning of the drought period is not likely to act until the drought breaks, and this may cause the growing-stage to be prolonged into the ripening-period with the consequences mentioned before—'second growth'. The safest form of nitrogen for after-dressings is undoubtedly nitrates. The question has been raised regarding the efficacy of complete fertilizer as after-dressing, and instances have been quoted of benefits derived from it. In view of the lack of mobility of phosphoric acid and potash it is unlikely that these constituents have much effect in the subsequent improvement of the crop, as they can never be worked down into the soil without grave risk of injury to the roots. The benefits observed from such after-dressings are probably due entirely to their nitrogen-content, whilst the phosphoric acid and potash are wasted. With severe eelworm-injury, however, the

complete fertilizer will be beneficial, as all the feeding-roots will lie near the surface.

Pests and Diseases

This also is a very wide subject and the following remarks are not comprehensive.

Eelworm.—The most pernicious soil pest is the root-knot eelworm (*Heterodera marioni*). When once established in the fields it virtually means the end of successful tobacco culture, and the greatest precautions should be taken to avoid introducing or extending this pest. Research on the eradication of eelworm has been extensively pursued, but no method has been found which is really practicable in the field. The precautions to be taken are:

1. The nursery-beds should be well burnt, whether these beds are on virgin land or have been previously used for nurseries.

2. After the first pulling from the seed-bed, any later plants should be examined and rejected if root-knot is observed. No chemical treatment of the plants will destroy the pest when it is once established in the roots, without the destruction of the plant itself.

3. An ample 'yardage' of nurseries should be sown in succession to allow for some to be rejected, and for the purpose of supplying blanks in the field. It is very risky to draw such supplies from old nurseries, or to obtain them from neighbouring farms, as they may be old plants and probably infected by the eelworm.

4. As soon as all necessary plants have been drawn from the nursery, the remainder should be pulled out and destroyed, and the nursery land planted up immediately with some immune crop.

5. If infected plants are discovered growing in the field in spite of the planter's vigilance, he must realize that unless special attention is given, his crop may become a complete failure, for eelworm destroys the ability of the roots to carry out their function. The only hope in such a case is to assist the plants to develop new roots, and to keep this development a little ahead of the pest. Earth should be drawn up round the stem, and the operation repeated weekly throughout the growth of the plant. Such soil will have the greater benefit if enriched with complete fertilizer. The signs of eelworm-attack are fairly well known, and in case of doubt a stalk should be pulled up here and there and the roots examined.

6. After harvest all stalks should be pulled out as cleanly as possible, dried in the sun, and burnt.

Cutworm.—The larvae of the sundry insects which have developed in the soil become active about the time when the tobacco is transplanted, and severe attacks have occasionally been traced to the preceding crop. If a green manure has been ploughed in rather late in the previous season, so that rotting down has been delayed, it is probable that severe cutworm injury will occur in the succeeding tobacco crop.

Leaf-eating caterpillars.—Should any outbreak occur in the nurseries one concludes that they have not been adequately covered by cheese-cloth, which would have excluded the moths responsible for these pests. Poison sprays may have to be resorted to in the nursery, but on no account should such materials be used in the field. Any leaves

which bear suspicious stains suggesting spray residues may result in the rejection of the cured leaf by the buyer. Hand-picking of caterpillars, grasshoppers, &c., is necessary. Generally speaking, the severity of insect-injury depends on climatic conditions.

Bacterial and fungoid diseases.—Provision against these must begin in the nursery, and the plants should be sprayed at intervals of 5–7 days with Bordeaux mixture. At the time of transplanting, all spotted leaves should be removed and destroyed, as these are potential sources of infection. Any mild outbreak in the field should be dealt with in the same manner, as it is far easier to check disease at an early stage than when it has reached serious proportions. Climatic conditions have a great influence on disease-outbreaks, and there seems little doubt that there are conditions and phases of susceptibility to disease in the plant itself. Periods of high humidity and misty weather favour their spread more than actual rains, and it is thought that mist in particular assists disease-spores to spread over the leaf, and gives them ample opportunity to germinate, whereas rain would probably wash them off. Plants which have received heavy nitrogenous manuring are particularly susceptible, possibly because of the preponderance of large, watery cells with soft walls. At the ripening-stage, the leaf is very susceptible to disease. Spots often appear in the early stages of curing, even when apparently clean leaf was put in the barn. Such spotting has been traced to the same organisms which produce leaf-spot in the field, and the curing barn has merely acted like an incubator in developing the spores. No method is known of preventing the development of 'barn-spot', as the organism is more difficult to kill than the leaf itself. The early stages of curing must be carried out below a certain temperature, and this is far below the lethal temperature of the disease-spores.

It has been observed that, provided there is ample sunshine between showers, a crop will remain clean in spite of moderately heavy rainfall. The crop may become badly diseased under smaller rainfall if sunshine is deficient, as in misty weather. One may say that provided the leaf dries between showers, disease-organisms are at a disadvantage.

Seed should always be disinfected before sowing to get rid of any spores that may be resting on the outer coat.

Virus diseases.—Diseases of the mosaic type cannot be checked in an infected plant, and due care should be taken to avoid their introduction and spread. Ordinary mosaic is highly infectious, and may be carried to every plant along a row and, indeed, to every plant in the field from the hands of the labourers. A rule should be made that an infected plant must never be touched by the ordinary labourer. Leaf-crinkle was proved by Dr. Storey to be a virus disease transmitted by a small, white fly. This disease cannot be transmitted from the hands of workmen. Its control has been effected by the destruction of the host plants on which it subsisted from one season to the next. The commonest source of infection was found to be old tobacco fields and nurseries which through negligence had not been uprooted after the previous crop.

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FORAGE-CROP IMPROVEMENT IN WESTERN CANADA FOR DRY-LAND AGRICULTURE

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IN a previous article [1] dealing with forage crops in western Canada, an attempt was made to outline the present status of forage-crop production under dry-land conditions, and the methods and practices which have been most successful in the different soil-climatic zones in that part of the Dominion. If this is read in conjunction with the present paper it will provide a background and perspective for an understanding of the objectives in such efforts as are being made to obtain better strains of grasses and legumes for the type of agriculture peculiar to the country. Whatever interest there may be for readers in other countries in the work which has been undertaken on crop-improvement in western Canada, and in the results accruing therefrom, this is sure to be increased if there is at the same time some appreciation of the precise nature of the natural environment, especially of the large part played by climatic factors in the adaptation and utilization of the crop plants.

Ability to persist without injury under exceptionally dry conditions and severe winter temperatures, which occur periodically, is the first essential of a satisfactory species or variety. This is so true of western Canada that crop-improvement becomes as much a study of plant-adaptation as of plant-breeding. In the first place, one has to work with highly adapted species, and sometimes, after years of intensive breeding and selection, one's best reward is a new appreciation of the essential agronomic value of a particular species or variety for this or that soil-climatic zone, or for a special purpose. This has been the case, to a greater or less extent, with all of the major grasses and legumes. An effort to improve these crops has gone hand in hand with an intensive study of their growth-characteristics, with the result that marked progress has been made towards zoning the country with respect to the adaptation of species. This preliminary, but nevertheless difficult, phase in the process of crop-improvement is of great importance in a country so large and exacting as is western Canada, and it is this feature of the crop-improvement work which certainly must rank with any progress in plant-breeding that has been achieved.

In the article previously referred to, it was pointed out that climatic conditions in western Canada limit the choice of forage crops for the most part to three grasses and two legumes. These are brome-grass, *Bromus inermis*; slender wheat-grass, *Agropyron tenerum*; crested wheat-grass, *Agropyron cristatum*; alfalfa, *Medicago*; and sweet clover, *Melilotus*. Other forage crops, grown to a small extent in limited areas, include timothy, red clover, and maize, and to these must be added also the cereals, which are grown most extensively. The present discussion of crop-improvement deals only with the two legumes and three grasses referred to above.

Alfalfa.—For many years western Canada has produced almost all the alfalfa seed it needs. The seed-stock came originally from Minnesota, having been introduced from Europe by a farmer named Grimm. It was subjected to natural selection on his own place for a period of fifty years, and seed from this source became known as the Grimm variety. For many years almost the only source of Canadian-grown seed was to be found in a certain district of southern Alberta, where the Grimm variety was produced on irrigated land.

Twenty-five years ago agronomists recognized that one day alfalfa would become an important crop, but there was some doubt of its winter-hardiness, and its range of adaptation was not well understood. It was generally conceded, however, that this crop had greater potentialities than any other perennial legume for an area like western Canada, with its rigorous winter climate and limited precipitation, but where the soil was generally favourable for its culture. For these reasons an extensive programme of improvement was undertaken by the Saskatchewan Agricultural College long before alfalfa began to be grown by farmers to any appreciable extent.

The first step was to bring in from many sources some twenty-five of the hardiest varieties or regional strains. The less adapted of these were soon eliminated by winter-killing, and eventually 1,300 selections were obtained representing single plants which had survived severe winter conditions. These were studied in clonally-propagated rows, selfed progenies, and progenies from open-fertilized seed. After several years of work, fourteen of the best strains were retained, and these were subjected to four generations of inbreeding with selection within the self-fertilized lines. The results of this study from the standpoint of yield and seed-production have been discussed elsewhere [2, 3, 4].

The results of selfed-line breeding with alfalfa in these experiments was not impressive as a practical method of improvement. Vigour of growth, as measured by yield of herbage, was reduced on the average by 46 per cent. Reduction in yield of seed was still more pronounced, amounting on the average to 78 per cent. The accompanying table gives the distribution of 61 fourth-generation selfed lines of alfalfa according to seed-yields expressed in per cent. of the mean yield of 18 check plots of the standard Grimm variety:

Seed-yield Classes

Median values . .	5	15	25	35	45	55	65	75	85	95
No. of selfed lines . .	20	18	8	6	2	1	2	2	2	0

Although it was found that inbreeding of alfalfa resulted usually in pronounced loss of vigour, it should not be concluded that this will always be so. Although the experiment occupied approximately one to two acres of land per year, the number of selfed lines must be regarded as relatively few, and all of them, except one, originated with the Grimm variety. Tysdal [5], on the other hand, working with selections of Turkestan alfalfa, obtained some selfed lines which were as productive as the parent sort. It seems probable that the difference between the

results in these two instances was due to a fundamental dissimilarity in the breeding-material.

Considering the physical difficulty of handling more than a few score selfed lines of alfalfa, the reduction in vigour which usually accompanies inbreeding, and the pronounced effects of inbreeding on seed-production, the method of 'strain building' described by Jenkins [6] would seem to have wider application. This admits of various methods of selecting parent plants and different systems of mating, and it aims to maintain the maximum vigour, as far as this is consistent with progress towards the desired result. The important thing, of course, is a satisfactory method of evaluating the breeding-potentialities of the parent plants. The method which seems to be most promising for this purpose is to determine the 'inherent' and 'combining' values of the parents by comparing their progenies produced from 'selfed' and 'out-crossed' seed, respectively.

Hand-in-hand with the breeding-programme, an effort was made during twenty years to improve the local adaptation of the original Grimm variety by a systematic process of mass selection. This resulted in a strain of Grimm alfalfa, designated 'Sask. 451', which is distinctly more winter-hardy but not more productive. The only change in appearance was a pronounced 'lightening' in flower colour, the mass effect being very noticeable. Seed of this mass-selected strain has been distributed quite widely and has proved very satisfactory; but as a variety it could not compete successfully with the original Grimm variety for the reason that seed of the latter was produced in such relatively larger amounts on irrigated land in southern Alberta that it dominated the seed-supply.

During the last ten years, however, the problem of winter-hardiness has become less urgent. There may be several reasons for this. In the first place the Alberta-grown Grimm alfalfa seed also has been subjected to rigorous climatic conditions which, through natural selection, may have increased its winter-hardiness; secondly, the area which is now recognized as best suited to the alfalfa crop has normally a good snow cover, and conditions generally are favourable for the winter survival of perennials; and lastly, there is a better understanding of the factors making for successful alfalfa culture. To the writer, this last consideration seems to be the most important. Generally speaking, alfalfa seed grown in western Canada now appears to be sufficiently hardy for all practical purposes.

As previously indicated, the irrigated land in the neighbourhood of Brooks, Alberta, produced the bulk of alfalfa seed used in western Canada for many years. Manitoba and Saskatchewan were thought not to have favourable conditions for seed-production. During the last few years this situation has radically changed until now Saskatchewan produces more alfalfa seed than Alberta, and Manitoba produces considerable quantities. Nearly all of the seed is of the Grimm variety. It is of interest also that, contrary to expectations, this development has occurred in the northern park-belt rather than in the southern plains, and recent observations would indicate that the leached grey soil in Zone 4 is likely to give consistently larger crops of alfalfa seed than the black soils of the parkland in Zone 3 (see sketch-map of major soil zones [1]).

The problem of improving alfalfa from a seed-production standpoint has received considerable attention. If alfalfa could be made to produce seed more consistently, the cost of seed might thereby be reduced—an important consideration—and the growing of seed placed on a profitable basis. Stabilization of seed-supply of an adapted variety would be an effective means of promoting a wider use of the crop.

The only tangible result of the extensive alfalfa-breeding programme outlined above is a strain of Grimm alfalfa designated 'Sask. 666'. This was released some years ago, and reports of its performance have been quite favourable. Like a number of other strains of variegated alfalfa, such as Baltic Cossack and Sask. 451, it has not been sufficiently superior or distinctive as compared with Canadian-grown Grimm to stimulate seed-production as a separate variety to a point where it has become available to the seed trade in quantity. The strain Sask. 666, originating with a single plant out of the Grimm variety, was selected originally as a consistently high seed-producer. In the process of seed-multiplication this characteristic was lost to some extent, presumably as a result of inbreeding resulting from self-pollination. Subsequent work has indicated that the high seed-production exhibited by the original plants was probably due to automatic tripping of the flowers. However, it did not reproduce this characteristic to the same extent under isolation.

Following this lead, an attempt is now being made to develop seed-production by a method which appears quite promising. Eight unrelated mother plants of the Grimm variety have been selected which produce seed abundantly and consistently by automatic tripping of the flowers. These have been synthesized into a single strain by crossing, the object being to concentrate the autogamous character and maintain maximum vigour. Progress reports of this study have appeared in three publications [4, 7, 8].

We now think that the Grimm variety of alfalfa cannot be further improved for use in western Canada at the present time, except with respect to seed-production. There is need, however, for a one-cut alfalfa and for types that are better adapted for pastures. These objectives are most likely to be attained through new introductions, such as 'Ladak', which is outyielding the Grimm variety at the first 'cut', and by selections and hybrids of *Medicago falcata*, which are low-growing and self-propagating by means of root-stalks.

Sweet Clover.—The importance of sweet clover as a hay, pasture, and soil-improvement crop in western Canada is ample justification for the considerable effort which has been made to improve it. The first extensive introduction of sweet clovers was made in 1916. Among these was a sample of seed from Prof. N. E. Hanson, of the South Dakota Agricultural College, who had obtained it in northern Siberia on one of his trips of exploration for the United States government. This proved to be a white-flowered, semi-dwarf, early maturing, five-stemmed uniform strain of exceptional winter-hardiness. It was subsequently increased at Saskatoon, and released to farmers under the name 'Arctic'. Since that time Arctic has been the best all-round variety of sweet clover in western Canada. With a rapid increase in sweet-clover acreage, many carloads

of common white-blossom sweet clover seed were brought in annually from eastern Canada and the United States, so that the Arctic variety now occupies only a portion of the acreage, making it more and more difficult to produce seed which could be certified as true to variety.

Many species, varieties, and strains of sweet clover have been studied at Saskatoon since 1920. The majority of these are coarser, taller, and less satisfactory than the Arctic variety. White-flowered sweet clover is grown much more extensively than the yellow-flowered sorts, the chief objection to the latter being their tendency to volunteer from shattered seed, the yellow flowers producing the appearance of mustard in subsequent crops of cereals. This is considered objectionable. Several distinct strains of yellow sweet clover have been developed but none of them has been established commercially.

For a concise outline of the objectives and methods used for improving sweet clover at the Dominion Forage Crops Laboratory, Saskatoon, Sask., the reader is referred to a recent article by Stevenson [9]. This paper also describes briefly the varieties that have originated as a result of this work, and includes a fairly complete list of literature references. A few comments on this work, therefore, is all that is needed.

The dwarf strains of white-blossom sweet clover, represented by the variety 'Alpha', are characterized chiefly by their numerous fine, short, leafy stems, which originate at the crown. The value of the shorter and finer herbage from the standpoint of hay-quality and ease of handling is best appreciated in parts of the black-soil zone where common sweet clover grows so tall and coarse that it is harvested and cured with difficulty. In the semi-arid plains of the West, on the other hand, the dwarf types tend to be too short in dry years. Here there is need for taller varieties, but similar to Alpha in fineness of stem. Such varieties are in sight as a result of crosses between the dwarf and tall-growing types. Some of these plants in the third hybrid generation are almost twice the size of the dwarf plants and possess the fine-stemmed, leafy habit of growth.

The Alpha variety has been shown to contain only about one-half as much coumarin as that of common sweet clover. It is distinctly less bitter to the taste, and therefore more palatable. Rightly or wrongly, sweet clover has long been criticized for its bitter taste, and progress in the development of strains that are free, or relatively free, from coumarin is regarded as a step in the right direction. Stevenson and Clayton [10] have recently discussed the results of their investigations during the last two years on coumarin in sweet clover, especially in relation to selection and breeding.

Other studies with sweet clover that may be mentioned concern pollination and fertilization, natural crossing, abnormal seed-development, inter-specific and inter-generic crossing, seed-mottling, inheritance of flower-colour, and inheritance of the dwarf branching habit of growth.

Awnless Brome-grass.—Awnless brome possesses most of the qualities which should characterize a thoroughly satisfactory grass for hay and pasture in the greater part of western Canada. It is highly adapted to the parkland soils and adjacent plains, but it requires more moisture than is sometimes available in the semi-arid sections.

The strongly spreading underground stems of brome-grass make it objectionable to many grain farmers, especially those on black 'parkland' soils and heavy clay soils. The crop becomes sod-bound within one or two seasons after the year of seeding, and this results in greatly reduced productivity. When the land is ploughed in preparation for a crop of cereals, the sod does not easily disintegrate, and the grass tends to re-establish itself in the soil by means of the stolons. In this behaviour the brome resembles couch grass (*Agropyron repens*), but in most parts of western Canada it is not so difficult to eradicate as the latter, and in fact does not present a serious problem when proper methods are followed.

During the last twelve years a sustained effort has been made to develop strains of brome-grass that would be characterized by a non-spreading habit of growth. Starting with a nursery of selected plants, the inbreeding method was adopted. Selfed seed is rather difficult to obtain, but a technique was found which proved successful under relatively dry atmospheric conditions [11]. Approximately 100 selfed lines were grown each year.

After four generations of inbreeding there was marked reduction in vigour of growth in most of the lines, but continuous selection towards a non-spreading type proved effective. Several strictly non-spreading lines were obtained, but these have been discarded in favour of lines with restricted spreading-habit. One of these gives much promise of being a very desirable sort, and the seed is being multiplied.

The non-spreading types of brome-grass are characterized by short underground stems, which emerge as new shoots close to the plant. This habit of growth results in plants that are compact with closely spaced culms. Selection for the non-spreading habit fortunately gave also more compact plants, and plants which were invariably more leafy.

A mixture of the non-spreading strain of brome-grass and alfalfa seeded at 25 and 5 lb. per acre, respectively, is expected to provide the best all-round hay and pasture crop for the parkland soils of the three western provinces.

Slender Wheat-grass.—This indigenous species was first cultivated in 1885. Tests conducted at the Dominion Experimental Farm, Brandon, Man., indicated that this grass possessed valuable characteristics as a cultivated crop. It rapidly became the most popular grass for hay throughout the West.

Improvement work began in 1913 when Dr. M. O. Malte [12], then Dominion Agrostologist, made single-plant selections from the numerous forms which he found growing in the neighbourhood of Edmonton, Alberta. When Dr. G. P. McRostie took over the work at Ottawa in 1922 he received from his predecessor 'a few superior strains of slender wheat-grass'. These were tested at the Dominion Experimental Station, Scott, Sask., one of them later being released as a combined hay and pasture type under the variety name 'Grazier'. Another strain known as 'Fyra' was distributed generally in 1925 by the Field Husbandry Department, University of Alberta. The latter variety was the best of a number of Ottawa strains tested at that Institution.

Improvement of slender wheat-grass was begun by the author in 1922

at the University of Saskatchewan. This breeding-project resulted in an improved strain named 'Mecca', pure seed of which is available. A paper published by the author [13] in 1929 gives an outline of the history of the breeding of slender wheat-grass and its status at that time, together with a full account of the development of the Mecca variety.

The Dominion Experimental Station at Scott, Sask., is located in a district which is especially well adapted to the growing of slender wheat-grass. Large numbers of lines have been tested there over a period of years. Three new strains have been selected and increased, and these, together with the three improved varieties mentioned above, are now being compared in special tests at Branch Experimental Stations in the three western provinces. In the meantime, brome-grass and crested wheat-grass have gained in popularity, whilst the use of slender wheat-grass is on the decline, for the time being at least.

Crested Wheat-grass.—For several years following 1915, when the first introductions of crested wheat-grass were made, we were but mildly interested in this species. Only after a succession of very dry seasons did we begin to appreciate how valuable it could become as a cultivated grass for hay and pasture in the semi-arid sections. Many years were devoted to a study of its natural range of adaptation, longevity, drought-resistance, root-development, response to continuous grazing under range conditions, and the best methods of securing good 'catches'. Crested wheat-grass is just now coming into general use. In 1935 well over 300,000 lb. of seed were produced for sale, mostly in Saskatchewan. It is estimated that 90 per cent. of this consisted of the improved 'Fairway' strain, 50,000 lb. of which were sealed in the sack as registered seed. That the demand for seed is far from being satisfied is indicated by the fact that prices paid to growers ranged from 28 cents per lb. for commercial crested-wheat seed to 45 cents for registered seed. Yields of 300 to 800 lb. of seed per acre have been quite common during the past season.

The Fairway strain of crested wheat-grass differs markedly from that of any of the numerous introductions which have been tested, especially with respect to its non-tufted habit of growth, the broad dense type of head, which always carries short awns, and the relatively small seed, as compared with that of ordinary crested wheat-grass. In the very dry ranching areas, where the ground-cover of native grasses is normally sparse, the Fairway strain probably has little advantage over the common sorts, but where the available soil moisture is a little more plentiful, the Fairway strain makes a closer turf and a finer growth, which is advantageous, especially for grazing. At Saskatoon it has consistently outyielded the tufted and taller types.

It has been shown also that crested wheat is a very useful turf grass for lawns, town boulevards, playgrounds, and fairways in the dry areas of western Canada, where appliances for artificial watering are not available. For these purposes the Fairway strain is especially desirable, as it makes a smoother and less tufted turf.

Crested wheat-grass produces seed almost entirely by cross-fertilization. Inbreeding results in pronounced loss in vigour of growth, and

many of the inbred lines contain albino seedlings. The species is conspicuous for its very wide range of variability in plant-type. It has been rather surprising, therefore, to find that the Fairway strain has retained its distinctive characteristics. Since the early breeding nurseries contained many introduced strains, occasional admixtures of other plant-types due to natural crossing might have been expected. The explanation seems to be that the Fairway strain has only 14 chromosomes, whereas the taller tufted types have 28. The chromosome counts were made but recently, and on only a few individuals, but if this holds generally, as we believe it does, there is a reasonable chance that natural crossing does not take place between the Fairway strain and dissimilar types of crested wheat. It follows also that the original mass selection was probably made from a single introduction. Unfortunately, all of the records were lost by fire in 1925; but since there were several hundred single plants each, of several introductions in the breeding nursery, this might easily have been the case. This is not surprising since any improvement-work which has been attempted in recent years has always led us to select within the Fairway rather than any other strain. Its superiority in single-plant nurseries, as well as in test plots, at Saskatoon is very obvious.

The results of investigations with crested wheat-grass have appeared in two bulletins [14, 15]. The later publication supersedes the first.

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THE FEEDING-VALUE OF PASTURES SOWN WITH DIFFERENT STRAINS OF GRASSES AND CLOVERS

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DURING the present century considerable interest has been taken in the improvement of grassland. A very large number of the investigations made have, however, been carried out on small plots, the results being expressed in terms of hay or dry grass. From such experiments one can calculate the monetary value of improvements on hay-fields, hay being a marketable product. In the case of grazing-fields, however, animal products—milk, meat, and wool—and not grass, are the marketable materials. Thus, in order to ascertain the value of any improvement in a pasture the herbage must be converted into these products, and the improvement measured either by the live-weight increase or by the milk-production of animals grazing on such pastures. As both these products are marketable it is possible, once the yields are known, to calculate whether certain improvements are economically sound at any given moment.

The first experiment designed to express the increased value of improved pastures in terms of animal products was initiated by Somerville [1] at Cockle Park in 1897. In that experiment the improvement resulting from the use of manures was shown as the increased live-weight production obtained, compared with that of the unimproved sward. This was further expressed in money value, 1 lb. increase in live-weight being reckoned to be worth 3*d*. Following Somerville's experiment several others were started on similar lines between 1900 and 1904 [2], and these also expressed the improvements effected by manures as live-weight increase of sheep. In experiments carried out later cattle were used, the improvements due to manuring being measured by milk-production [3, 4, 5] and by increase in weight [6].

Until the last few years little was known of the relative feeding-value of different grasses and clovers, although it was generally realized that the inclusion of wild white clover in a seeds-mixture had a marked effect on the resulting sward [7, 8, 9]. Somerville [2] attributed part of the increased mutton-production on the slagged plots to the increase in white clover, but the value of this species could not be definitely ascertained as it was not known how much was due directly to slag and how much to white clover. Roberts [10], dealing with a pasture in its third and fourth harvest years, showed that the inclusion of wild white clover gave an increase of 36 per cent. and 22 per cent. respectively in the live weight of cattle and sheep. The present writer [11], using sheep only, showed that swards consisting chiefly of perennial rye-grass with wild white clover, and bent with wild white clover, gave about 200 lb. more increase in weight than cocksfoot plots which contained little or no white clover. This difference represented an increase of over 70 per cent. It was also shown that the increased live-weight obtained from

the white-clover plots was greater than would be expected on the basis of increased yield of herbage as such; thus suggesting that a mixture of grasses and clover has a higher feeding-value than a mixture consisting of grasses only.

To obtain more information about the feeding-value of different species, and groups of species, a new experiment was laid out on a 10-acre field in May 1931. The field had been through the ordinary farm rotation, viz. grass followed by cereal crops in 1928 and 1929, a root crop in 1930, and 'seeds' sown under barley in 1931. Eight acres of this field were divided into 48 plots, each measuring 18 by 45 yds. ($\frac{1}{8}$-acre). Eight different seeds-mixtures were sown, each being replicated six times. The experiment will be dealt with in two parts: Part I relating to six ultra-simple seeds-mixture, and Part II to two complex seeds-mixtures.

Part I. EXPERIMENTS WITH VERY SIMPLE SEEDS-MIXTURES

The six simple mixtures were made up as follows in lb. per acre:

Mixture 1.	Perennial rye-grass*	35
Mixture 2.	Cocksfoot†	35
Mixture 3.	Perennial rye-grass*	17½
	Cocksfoot†	17½
Mixture 4.	Perennial rye-grass*	30
	Wild white clover	5
Mixture 5.	Cocksfoot†	30
	Wild white clover	5
Mixture 6.	Perennial rye-grass*	15
	Cocksfoot†	15
	Wild white clover	5

* Seed from Kentish old pastures.

† Strain of cocksfoot (S 26) bred at the Welsh Plant Breeding Station.

Although the nurse crop (barley) gave a very heavy yield, yet the 'take' of the grasses was exceptionally good. A close examination of the sward in April and early May of the first grazing season showed the presence of the white clover as very small plants or seedlings on the plots where it was sown, but none could be found on the other plots. However, owing to slow growth its contribution to the pastures where it was sown was negligible until the end of May and early June of the first grazing-season. After that period, and during the following three seasons, its contribution to the herbage of the plots where it had been sown was considerable, though it varied from plot to plot and from year to year. This point will be dealt with in greater detail in a subsequent communication. It will suffice here to state that the contribution of white clover was negligible on almost all plots except those where it had been sown, and that it varied in amount from plot to plot even where it had been sown, being far more productive when associated with perennial rye-grass than with cocksfoot; in fact, there was only a trace of it on certain cocksfoot plots in the first two years.

Stock used and method of grazing.—Grazing was carried out exclusively by sheep, which were tethered: about 110 lambs were bought every autumn and wintered on an adjoining farm; they were brought from

their winter quarters about a week before the grazing on the plots was begun. During this week they were weighed on three successive mornings after a fast of 16 hours. Occasionally there was a fourth and even a fifth weighing if the first three weighings did not agree. Any sheep that showed signs of being abnormal in any way were rejected, together with those that were outstandingly large or outstandingly small. The remaining sheep were then divided into eight groups of twelve, each group being similar in size, type, and condition.

Grazing usually began in the latter part of April, one pair of sheep being tethered on every plot that had a sufficient growth of herbage to maintain them at that time; the remainder of the plots were stocked later. Each pair of sheep was shifted forward 2 yards each morning and each night. The length of chain was such that only half the width of the plot was grazed when the sheep were shifted forward, the other half being grazed as the animals moved in the opposite direction about 10 days later. This arrangement made it possible for all areas to have a 3 weeks' rest between each grazing. Usually during May and June each plot was grazed by a pair of sheep, but in July and August it frequently happened that a number of pairs had to be removed owing to a shortage of food. The object in view during the grazing was to keep the number of sheep at such an intensity as to avoid any wastage of herbage, and at the same time to satisfy the needs of the sheep. All sheep that were removed were again weighed on three successive mornings, in each case after 16 hours' fasting, and any further growth of herbage on those plots would be shared between the most needy pairs of the other five replicates. It was found in some mixtures that towards the end of August and during September three pairs of sheep could eat all the herbage on the six replicates of their mixture, whereas other mixtures were quite able to supply the needs of the six pairs of sheep. In addition to the first and final weighings, the sheep were also weighed when released for shearing, and again prior to dipping; all weighings followed a 16-hours' fast.

Discussion of Results

Live-weight increase

(*a*) *Effect of wild white clover on live-weight production.*—The increase in live-weight of the sheep on the different mixtures is shown in Table 1. It is seen that in four years the sheep grazing on the plots in which wild white clover had been sown gained on an average 224 lb. per acre more than those grazing on the plots where the wild clover had been omitted from the seeding. This represents a difference of 56 lb. per acre per year in favour of sowing wild white clover.

A comparison of the live-weight increase of sheep grazing on the plots sown with grasses and wild white clover and those sown with grasses only is also shown in Table 2, in which the figures represent the percentage increases due to wild white clover.

Thus, during the whole period of four years, the increase in live-weight due to the clover was much higher on the rye-grass plots than on the cocksfoot plots, the rye-grass–cocksfoot plots being intermediate.

TABLE 1. *Increase in Weight of Sheep grazing on Swards of Different Composition*

(*lb. per acre per annum*)

Plot	*1932*	*1933*	*1934*	*1935*	*Total for four years*
Rye-grass	263	169½	170¾	195¼	798½
Cocksfoot	240	165¼	160½	164	729¾
Rye-grass and cocksfoot	260	179¾	175½	187¼	802½
Average of plots without clover	254¼	171½	169	182¼	777
Rye-grass and wild white clover	313	245	263¼	244¼	1065½
Cocksfoot and wild white clover	279	186	232½	203¾	901¼
Rye-grass, cocksfoot, and wild white clover	285	223	263	265½	1036½
Average of plots with clover	292	218	253	238	1001

TABLE 2. *Percentage Increases in Live-weight Production obtained on the Plots Sown with Grasses and Wild White Clover above those obtained on the Plots Sown with Grasses only*

Year	*Percentage increase due to wild white clover on*			
	Rye-grass	*Cocksfoot*	*Rye-grass and cocksfoot*	*Average*
1932	19·0	16·2	9·6	15·0
1933	44·7	12·5	24·0	27·1
1934	54·1	45·0	50·2	49·8
1935	25·1	24·4	41·7	30·6
Average	33·4	25·0	29·4	28·8

A comparison of the different years shows that the highest percentage increase due to wild white clover was obtained in the third grazing-season (50 per cent.) and the lowest in the first grazing-season (15 per cent.). The second and fourth grazing-seasons gave on the average a similar increase, yet wild white clover contributed far more to the live-weight increase of the rye-grass plots in the second season, whereas on the cocksfoot and the rye-grass–cocksfoot mixture it was much more effective in the fourth year. This corresponds roughly with the productiveness of the white clover, the third year being the best and the first year the poorest for the growth of clover. In addition the amount of white clover on the rye-grass plot greatly exceeded that on the other plots in the first and second years, but by the fourth year it had disappeared from two of the rye-grass plots, whereas its productivity on the cocksfoot and rye-grass–cocksfoot plots was better maintained.

(*b*) *The effect of species on live-weight production.*—The superiority of rye-grass for live-weight production (Table 1) is shown more strikingly in Table 3, where all values are given on the basis of cocksfoot = 100.

TABLE 3. *Comparative Live-weight-increases of Sheep grazing on Plots of Rye-grass and Cocksfoot*

(*Cocksfoot in all cases* = 100)

	Grasses only	*Grasses and wild white clover*	*Average*
Cocksfoot . . .	100	100	100
Rye-grass . . .	109·4	118.2	114·3
Rye-grass and cocksfoot .	110·0	115·0	112·7

Condition of sheep.—In addition to being weighed, all sheep were graded according to condition in 1932 and 1935. This was done at the final weighing. The animals were divided into three main grades as follows:

Grade 1: fat.
Grade 2: all fit for killing but slightly inferior to Grade 1.
Grade 3: stores and not suitable for killing.

Each grade was further subdivided, but these three main grades serve to show the trend of condition of the animals on these plots. In 1933 and 1934 the drought interfered with grazing, which was not continuous throughout the season in either year, so that grading would not have served any useful purpose.

The results of grading, given in Table 4, show the superiority of the clover over the non-clover swards, and of rye-grass over cocksfoot swards in the fattening of the sheep. This indicates that the higher live-weight increases obtained on certain plots, as shown in Tables 1, 2, and 3, were primarily due to fattening rather than to body-growth.

TABLE 4. *Condition of Sheep after grazing on Different Swards (Results for 1932 and 1935)*

	First grade	*Second grade*	*Third grade*
Rye-grass	7	8	9
Cocksfoot	0	11	13
Rye-grass–cocksfoot	6	8	10
Totals, plots without clover . . .	13	27	32
Rye-grass and wild white clover	11	12	1
Cocksfoot and wild white clover	7	12	5
Rye-grass, cocksfoot, and wild white clover . .	11	12	1
Totals, plots with clover	29	36	7
All rye-grass plots.	18	20	10
All cocksfoot plots	7	23	18
All rye-grass–cocksfoot plots	17	20	11

Carrying-capacity of the pastures.—In addition to differences in live-weight increments, it was found that certain plots were able to maintain the stock for longer periods than others. Although this is partly reflected in the figures for live-weight increase, yet earlier spring grazing and grazing available during periods of drought have a special maintenance-

value which should be calculated quite apart from production, as shown in Table 5. These figures indicate that the average carrying-capacity of the clover plots was 193 'sheep-days' per acre per year, or 14·5 per cent. greater than that of the non-clover plots. Within the non-clover plots, and also within the clover plots, the difference in the carrying-capacity of the various grasses was very small—less than 2 per cent.

TABLE 5. *Carrying-capacity of the Pastures in 'Sheep-days' per acre per annum*

	1932	*1933*	*1934*	*1935*	*Average per annum*
Rye-grass	1697	1156	948	1506	1327
Cocksfoot	1682	1190	894	1466	1308
Rye-grass and cocksfoot	1722	1190	948	1506	1341½
Average	1700	1179	930	1493	1325
Rye-grass and wild white clover	1872	1458	1160	1616	1526½
Cocksfoot and wild white clover	1822	1458	1114	1616	1502½
Rye-grass, cocksfoot, and wild white clover	1862	1458	1160	1616	1524
Average	1852	1458	1145	1616	1518
Average increase due to wild white clover	152	279	215	123	193
Percentage increase due to wild white clover	9·0	23·6	23·1	8·2	14·5

Roberts [10] states that in the experiment he described the extra live-weight increase was mainly due to a greater stock-carrying capacity on the wild white clover plots. In the present experiment, however, the clover plots compared with the non-clover plots gave on an average nearly 30 per cent. more live-weight increase, whereas the carrying-capacity was only approximately 15 per cent. higher. These data show that in addition to increased carrying-capacity the white clover had increased the feeding-value of the herbage. This is also borne out by the results of a previous experiment [11].

Rainfall during the Four Grazing Seasons, 1932–5

The experiment was conducted in a district situated about mid-way between Aberystwyth and St. Anne's Head, Pembrokeshire, where the nearest weather-recording stations are situated. The rainfall in inches between the 1st of April and the end of September for these two stations was:

	1932	*1933*	*1934*	*1935*
Welsh Plant Breeding Station*	16·97	8·94	19·10	26·14
St. Anne's Head*	14·31	13·10	11·41	14·86
Average	15·64	11·02	15·25	20·50

* These values were calculated from data extracted from the monthly weather reports of the Meteorological Office.

These figures show that the rainfall differed markedly at the two stations. Apart from 1934, however, the average figures as shown above

would give approximately the rainfall during the experiment. The rainfall for 1934 would be nearer to the value given for St. Anne's Head, or even less than that. This difference in rainfall, however, does not give a true picture of the wetness or dryness of the different years, 1933 and, especially, 1934 being classed as two dry years, whereas 1932 and 1935 would be classed as wet years.

The above tables show that in the comparatively 'wet' years (1932 and 1935) the average increase in weight per acre (all plots) was 241½ lb., whereas in the 'dry' years (1933 and 1934) it was only 203 lb. per acre. This represents an increase of about 19 per cent. more production in the wet years than in the dry years. The average carrying-capacity was 1,665 'sheep-days' in the wet years, and only 1,178 'sheep-days' in the dry years. This is equivalent to an increase of 41 per cent. in the carrying-capacity during wet years as compared with the dry years. Thus the greater growth of herbage in the wet years increases the carrying-capacity of the pastures more than their live-weight production. It is also seen that although the wet years have a greater total increase in live-weight, yet the live-weight increase per sheep-grazing-day was lower than in the dry years.

Part II. EXPERIMENTS WITH COMPLEX SEED-MIXTURES

In the second part of the experiment two complex mixtures were compared, one consisting mainly of indigenous grasses and clovers, the other of the ordinary commercial strains. The mixtures were made up as follows in lb. per acre:

	Commercial mixture	*Indigenous mixture*
Perennial rye-grass	14	12
Italian rye-grass	5	5
Cocksfoot	3	8
Timothy	4	2
Meadow-fescue	2	..
Crested dogstail	..	2
Rough-stalked meadow-grass	..	2
Wild white clover	..	2
Dutch white clover	1	..
Red clover	4	4
Alsike	1½	..
Trefoil	1	..

In the commercial mixture the red clover was composed of three parts broad red to one part of late-flowering red clover.

In the indigenous mixture the red clover was the Montgomery strain; white clover was all genuine 'wild' white; perennial rye-grass was obtained from old Kentish pastures; cocksfoot and timothy were strains bred at the Welsh Plant Breeding Station.

The mixture of commercial strains represents the average type of seeds-mixture sown by farmers in this area. Although the seeds-mixture varies from farm to farm, yet in a large number of lists examined it was found that commercial strains of rye-grass, cocksfoot, timothy, and meadow-fescue were used together with Dutch white clover, broad red

and late-flowering red clovers, alsike, and trefoil. Wild white clover, rough-stalked meadow-grass, and crested dogstail were nearly always excluded.

In the indigenous mixture a modified form of the Cockle Park mixture was sown as recommended by Stapledon and Davies [12]. Wherever possible improved strains were used, but with many species only the ordinary strains were available.

In the first grazing season four plots of each mixture were kept for hay and then grazed, and again in the fourth grazing season one plot of each was similarly treated.

TABLE 6. *Comparison of the Productiveness of the Commercial Mixture and the Indigenous Mixture as* (a) *Increase in Live-weight in lb. per acre;* (b) *Carrying-capacity expressed in 'Sheep-days', and* (c) *Yield of Hay on Ungrazed Areas (1932 and 1935)*

Mixture	*1932*	*1933*	*1934*	*1935*	*Total*
(*a*) *Increase in live-weight:*					
Commercial . . .	122	202½	192½	177½	694½
Indigenous . . .	156½	238½	227½	205½	837½
(*b*) *Carrying-capacity:*					
Commercial . . .	1,065	1,250	948	1,330	4,593
Indigenous . . .	1,215	1,458	1,160	1,430	5,263
(*c*) *Yield of hay* in cwt.:*					
Commercial . . .	21¾	..	..	4	25¾
Indigenous . . .	23	..	..	5	28

* On ungrazed plots.

A comparison of the production of these two plots is given in Table 6, from which it is seen that the increase in the live-weight of the sheep, the carrying-capacity, and the hay-production, were higher for the indigenous than for the commercial mixture for every year in which figures were available.

The total increased live-weight production for the indigenous mixture was about 143 lb. per acre, or about 36 lb. per acre per annum. This represents an increase of 20 per cent. over the commercial mixture.

The total increased carrying-capacity for the indigenous mixture amounted to 670 days, or about 168 sheep-days per acre per annum. This is equivalent to an extra carrying-capacity of about 0·46 sheep per acre for a whole year, or an increase of 14·6 per cent. over the commercial mixture. The hay harvested from the ungrazed plots in 1932 and 1935 amounted to 25¾ cwt. for the commercial mixture, and 28 cwt. for the indigenous mixture; the latter, however, was far more leafy and probably of greater feeding-value.

Fagan [13] has shown that grass leaves are more nutritious than stems. In addition, Stapledon [14] has established that the indigenous strains of grasses, particularly perennial rye-grass, cocksfoot, and timothy are far more leafy and longer lived than their commercial counterparts.

These facts are borne out by the present experiment, in that the indigenous mixture of grasses and clover has given higher increases in the live-weight of sheep than the commercial mixture.

Financial aspect of the results.—A comparison of the possible financial returns is shown in Table 7. In arriving at these figures it has been assumed that each pound of live-weight increase of sheep is worth 4*d.*, and that hay standing in the field is worth £2 per ton. These values must of necessity change with any fluctuations in market prices.

Although the mixtures of grasses and wild white clover cost considerably more than those not containing clover, the extra production

TABLE 7. *Financial Returns per acre for the Sum of Four Seasons*

	Cost of mixture	*Total live-weight increase lb. per acre*	*Value of live-weight increase at 4d. per lb. in shillings per acre*	*Value of hay in shillings per acre*	*Total value of produce in shillings per acre*	*Total value less cost of mixture*
	s. d.		*s. d.*	*s. d.*	*s. d.*	*s. d.*
(*a*) *Comparison of:*						
Grasses only	43 9	777	259 0	..	259 0	215 3
Grasses and wild white clover	62 6	1,001	333 8	..	333 8	271 2
Increase due to wild white clover	18 9	224	74 8	..	74 8	55 11
(*b*) *Comparison of:*						
Commercial mixture	22 0	695	231 8	51 6	283 2	261 2
Indigenous mixture	54 0	838	279 4	56 0	335 4	281 4
Increase of indigenous mixture over commercial	32 0	143	47 8	4 6	52 2	20 2
Simple mixture of rye-grass and wild white clover	62 6	1,065½	355 2	..	355 2	292 8
Increase of simple mixture over commercial	40 6	370½	123 6	−51 6*	72 0	31 6

* No hay cut; hence the value of hay cut on the commercial mixture is entered as a minus quantity.

of live-weight on the plots of the former more than repaid this increased original outlay; in fact there was a profit of about 56*s.* per acre in favour of wild white clover. In addition it should be pointed out that wild white clover had been sown at the unusually heavy rate of 5 lb. per acre in order to be certain of a sward rich in clover. It is very probable, however, that equally good results would have been obtained by sowing 2 lb. of wild white clover, thus reducing the cost of the clover mixtures by 15*s.* per acre.

If the ordinary farmer's mixture of grasses and clovers is taken as a basis, the mixture of indigenous strains of grasses and clovers, despite its higher seed cost of 32*s.* per acre, more than repaid this additional cost, and still left a profit of about 20*s.* per acre. The best return, however, was obtained from the simple mixture of perennial rye-grass and wild white clover. Though its seed cost was 40*s.* per acre higher than that of the farmer's mixture, yet it left a profit of 31*s.* 6*d.* per acre.

It will be noted that no value has been given to the extra carrying-capacity. Although this is partly reflected in the live-weight increase,

yet in the early spring and during periods of drought it has a special value, and at such times ½*d.* per sheep per day is not too much. In this experiment the extra sheep-carrying capacity is distributed over the growing-season, but is more pronounced during the critical periods mentioned above. On that account it would not be unfair to value this extra sheep-carrying capacity at about half the normal rate. This would increase the money value of the clover plots over the non-clover plots by about 16*s.*, giving a total in favour of sowing white clover of about 72*s.* per acre in four years. In the comparison between the commercial mixture and the indigenous and simple mixtures, both the latter plots would have an increased value of about 14*s.* per acre over the commercial mixture. This would bring the balance in favour of the indigenous mixture to 34*s.* 2*d.*, and that in favour of the simple mixture to 45*s.* 6*d.* per acre as compared with the returns of the commercial mixture. Thus the most economic returns financially and agriculturally have been obtained by sowing:

(*a*) wild white clover,
(*b*) indigenous strains of grasses and clover,
(*c*) rye-grass in preference to cocksfoot.

Summary

An account has been given of an experiment designed to test the value of different types of seeds-mixtures in the production of live-weight increments in sheep. It has been shown that:

1. Grasses in combination with wild white clover (*a*) were nearly 30 per cent. more productive in live-weight increments, and (*b*) had a carrying-capacity nearly 15 per cent. higher than those sown without the white clover.

2. Perennial rye-grass was about 14 per cent. more productive in live-weight increase but had the same carrying-capacity as cocksfoot.

3. A complex mixture of indigenous grasses and clover gave much larger increases in live-weight and also gave a higher carrying-capacity than a mixture of commercial strains.

4. The increase in live-weight of sheep per grazing day was greater in the 'dry' years than in the 'wet' years, yet the total increase in live-weight per acre per grazing-season was greater in the wet years; this being due to the longer grazing afforded during the wet seasons.

An attempt has been made to convert the results obtained into money value; this has shown that certain mixtures of grasses and clovers give far better returns per acre than others.

The experiment is still in progress; further results will be published in due course.

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THE YIELD AND COMPOSITION OF CUT PASTURE HERBAGE AT DIFFERENT TIMES OF THE DAY

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Introduction.—The amount of water in pasture herbage, as is well known, may vary appreciably during the day, depending largely upon the immediate weather conditions. This fact is naturally one of practical and economic importance in the conservation of grass by artificial drying, where a low moisture-content, or water ratio,[1] in which form it is usually expressed, means a saving in the costs of both carting and drying, and an increased output of dried material. For these reasons, and where preliminary drying in the field (*this J.*, 1936, 4, 145), is not practised it would seem advantageous to cut the grass at that time of the day when its moisture-content is lowest.

Although various workers have investigated diurnal variations in the water-content and in the composition of certain plants, most of their work has been concerned with variations as between day and night, and with plant-physiological problems having little direct bearing on the present question. The only relevant study of herbage plants, so far as the author is aware, was made in 1934 at Billingham, on herbage from the farm adjoining the factory of I.C.I. (Fertilizer and Synthetic Products) Ltd.[2] It was there found that the water-content of grass depended on the time of year, the nature and stage of its growth, and on the immediate weather conditions. On sunny days in May the water ratio fell considerably during the day, the lowest values occurring between 11 a.m. and 3 p.m., but on cold or dull days and at the end of the season, little diurnal variation occurred. Also, the moisture-content of older tissue was lower than that of young growth.

The object of the tests here described was to study diurnal variations in the moisture-content of grass under different weather conditions and at different times of the season, in order to ascertain the best time of day at which to cut grass for artificial drying. At the same time the opportunity was taken of studying whether, and if so to what extent, variations occurred in the yield of herbage cut, and in its contents of dry matter and nitrogen.

The Investigation.—The tests were conducted at Jealott's Hill on five days during the grass-drying season of 1935, all within a small area of good-quality pasture in Copse Meadow, on grass which was either being cut at the time for drying, or was at a stage of growth suitable for drying.

Three plots,[3] each 18 in. square and randomized in three blocks, were cut at 9.30 a.m. on each day, and further series of three plots were cut at 1½- or 2-hourly intervals throughout the day until 5 p.m., when the last plots were cut. Cutting was done by hand with a pair of sheep-

[1] Ratio of water to dry matter. [2] Private communication.

[3] The plots were laid out to avoid any side- or edge-effects, at least a 1 ft.-width of uncut grass being left around each plot.

shears, and the herbage was cut uniformly to within about 1 in. of ground-level. To facilitate easy and uniform cutting, a wooden frame of the size of the plot, with sides 2 in. wide and $\frac{3}{4}$ in. deep, was placed over the plot to rest on the grass without pressure at about $\frac{1}{8}$ in. above ground-level. The ends of the undisturbed grass within the frame were then held lightly, a few at a time, in the finger-tips, without any upward pull or downward thrust, which would be likely to alter the natural position of the lower parts of the shoots, and the grass was then cut with the shears held in the plane parallel to and just above the top of the frame, i.e. at about 1 in. above ground-level. The plots (except on one or two occasions) were all cut by the same person. In almost all cases the herbage was free from extraneous material; the cut herbage, however, was carefully looked over at the time of cutting, and any extraneous material removed.

The fresh herbage from each plot was weighed immediately after cutting, and then taken to the laboratory, where it was spread out in a thin layer, dried immediately to constant weight in the steam-oven, and the yield of dry matter thus determined. By drying the whole of the produce from each plot, any error in sampling the fresh grass was avoided. The percentage of nitrogen in the ground, dried material, was determined by the standard Kjeldahl method.

In many cases the grass held external moisture, which was not determined separately, and the figures given, therefore, include both the internal and any external moisture present. Visual and tactile observations were, however, made of the presence or absence of external moisture and of its approximate extent.

Conditions of Tests.—The tests were carried out at three periods of the season on the dates and under the conditions given below:

(i) May 20 and 21. First spring growth 6–8 in. high, consisting mainly of perennial rye-grass (34 per cent.) and meadow foxtail (35 per cent.) with a little of the former coming into flower, and much of the latter actually in flower. Tests carried out on consecutive days, the first wet, cold, and sunless, the second fine and sunny but cool, with a drying east wind. Field being cut for artificial drying at this time.

(ii) June 28. Growth 8–9 in. high, made since the May tests, and consisting chiefly of perennial rye-grass (47 per cent.) and Yorkshire fog (19 per cent.), both well in flower, with wild white clover (16 per cent.). Weather was warm and sunny. Field being cut for artificial drying at the time.

(iii) October 9 and 11. Growth made since June cut, but mainly new autumn growth made since August, following a dry summer, and consisting chiefly of perennial rye-grass (61 per cent.) and wild white clover (15 per cent.). 3–5 in. high. The first day was dull and windy with drizzle and rain later; the second was fine and sunny.

The meteorological readings on these days and the preceding day in each case are given in Table 1.

Soil moisture was not determined specially for this investigation, but measurements taken on adjoining pasture in connexion with other work

gave the following values for the percentage of moisture in the top three inches of soil, on, or a little before, the dates when the grass-cutting tests were made: May 20, 18·4; June 24, 19·0; Oct. 7, 25·1. On each day of the tests the soil was moist, and on no occasion did the soil appear to lack moisture needed by the grass.

TABLE 1. *Meteorological Readings*

Date	*Barometer*	*Humidity*	*Screen temperature*		*Rainfall*	*Sunshine*	*Wind direction and force*
			Maximum	*Minimum*			
	in.	%	° F.	° F.	in.	hr.	
May 19	29·89	73	53	30	0·21	0·2	S.E. 1
„ 20	29·75	83	55	41	0·91	0·5	Calm
„ 21	29·98	75	57	39	..	10·9	E. 4
June 27	29·95	91	67	56	..	1·5	S.W. 1
„ 28	30·25	74	75	47	..	14·8	Calm
Oct. 8	29·54	93	55	42	0·27	2·1	S.W. 3
„ 9	29·64	88	59	43	0·64*	0·9	S.W. 3
„ 10	29·28	85	57	49	..	7·6	S.W. 4
„ 11	29·75	80	58	43	..	8·9	S.W. 3

* Most of this rain fell after completion of test.

The soil in Copse Meadow is a medium loam overlying clay. The manuring of the pasture in 1935 consisted of 2 cwt. of sulphate of ammonia per acre, applied on April 15.

Results.—The results are tabulated in the appendix, and include: the yields (average values of the three replicate plots) of fresh herbage, dry matter, and nitrogen; the percentage of water in the fresh herbage with the corresponding water ratio; and the percentage of nitrogen in the dry matter; together with brief notes on the weather conditions during the intervals between the cuts, and on the presence or absence of, and the approximate extent of, external moisture on the grass.

(i) *May 20 and 21.* On the fine, sunny day (May 21), the percentage of water in the cut herbage decreased significantly[1] during the latter part of the morning, between 11 a.m. and 1 p.m., with the disappearance of the external moisture originally present, and thereafter, between 1 and 5 p.m., remained unchanged. The fall in the water ratio was from approximately 4·5 to 3·5. May 20 was wet and the grass held a considerable amount of external water throughout the day, but although this amount appeared to get less during the temporarily dry period between 11 a.m. and 1 p.m., no significant diurnal change in the percentage moisture-content of the herbage was observed.

The yield data are less easily interpreted. As is inevitable with pasture herbage, where the natural yield variation is always comparatively large, the yields of the replicate plots varied appreciably, and although the average values would seem to indicate considerable diurnal variations in

[1] The term 'significant' is used throughout in the statistical sense ($P = 0{\cdot}05$), in accordance with Fisher's analysis of variance.

the yields (whether expressed in terms of fresh herbage, dry matter, or nitrogen), the variations in the yields of dry matter and nitrogen did not attain a 20 to 1 level of significance. However, on both days there was an apparent progressive and substantial falling off in these yields during the morning, with the lowest yields of the day obtaining in the 1 p.m. cut, but on the rainy afternoon of May 20 the yields apparently increased again, and on the fine afternoon of May 21 remained practically constant at the midday level.

The percentage of nitrogen in the dry matter of the herbage varied appreciably from plot to plot, and at different times of the day, particularly on May 20. The observed diurnal variations were not significant on May 20, but on May 21 the fall in the percentage value in the middle of the day, from an initial value of about 2·8 to 2·5, was apparently just significant; the value increased again in the afternoon.

(ii) *June 28.* In this test the grass was more stemmy and mature than that of the May tests (though it was fresh growth made since these tests), as will be seen also from its lower nitrogen-content; also, growth was more uniform than in May, and the individual plots in consequence showed less variation in yield. Under these conditions, and on a warm, sunny day, the only significant diurnal change observed was a reduction in the percentage of water in the fresh herbage during the morning, as the dew disappeared; the fall in the water ratio was from 4·4 to 3·7 approximately. After midday the moisture-content of the grass remained unchanged. No significant change was observed during the day in the yields of dry matter or nitrogen, or in the percentage of nitrogen in the dry matter.

(iii) *October 9 and 11.* Under the autumn conditions of Oct. 9, during a dull but windy morning after rain overnight, the moisture-content of the herbage fell significantly, with the disappearance of the external moisture present, until the lowest value of the day was obtained in the 2 p.m. cut; the fall in the water ratio was from 5·1 to 3·3. When rain fell later the moisture-content increased to the value of the early morning. The test of October 11 differed from the four previous ones in that the grass initially held practically no external water; under these conditions and during a generally fine, sunny day, no significant change in the moisture-content of the grass was observed.

Growth in October was again somewhat uneven and the individual plot-yields in consequence were again somewhat variable. No significant change was observed in the yields of dry matter or nitrogen on Oct. 11, but on Oct. 9 (as on May 20 and 21) there was an apparently substantial reduction in the yield (whether expressed in terms of fresh herbage, dry matter, or nitrogen) in the middle of the day (between 11 a.m. and 2 p.m.), with an increase again (including increased yields of dry matter and nitrogen) in the later afternoon cuts. It is to be noted, however, that as on May 20 and 21, this apparent diurnal variation in yield does not attain the level of significance of 20 to 1, though the level attained on Oct. 9 falls little short of this value.

Neither on Oct. 9 nor 11 was there any significant change during the day in the percentage of nitrogen in the dry matter of the herbage.

Discussion

The significance of the percentage water-content of the grass in its conservation by artificial drying is well shown by the following figures:

Water, per cent.	85	80	75
Dry matter, per cent.	15	20	25
Water ratio	5·7	4·0	3·0

Thus a relatively small reduction in the percentage of water in the grass means a comparatively large increase in the proportion of dry matter which is being cut, collected, and carted, and a corresponding reduction in the amount of water which has to be evaporated per unit of dry matter present. The tests described have shown that under a variety of weather conditions and at different periods of the grass-drying season, a considerable reduction in the percentage of water in the grass normally occurs during the day, and that under the conditions investigated the percentage generally reached its lowest value of the day sometime between noon and 3 p.m. This reduction in moisture-content was apparently associated almost exclusively with the disappearance of external moisture usually present in the herbage early in the day, little or no change being observed when external moisture was absent.

For practical purposes, under conditions generally similar to those under which these investigations were conducted, it may be concluded that if the grass contains any appreciable amount of external moisture in the early morning, most of this moisture will have disappeared by about midday (unless it has rained meanwhile), and that any subsequent reduction in the moisture-content will be of little or no practical significance. The most suitable hours for cutting grass, under these conditions, to ensure a minimum moisture-content, would appear, therefore, to be from about noon or a little earlier, to 3 p.m. or later, should the grass remain free of external moisture. Where the grass is more or less free of external moisture initially in the morning, there will probably be but little advantage if cutting is postponed until later in the day. The general accordance of these results with those obtained under other conditions at Billingham (*v.s.*) in 1934 is noteworthy.

On none of the days when the tests were made was the weather hot, and the results, although apparently applicable to the weather conditions usually obtaining under grass-drying practice, cannot, pending further tests, be taken to apply to conditions of heat and drought in which there may be some diurnal variation in the internal moisture of the herbage, though no evidence of it was apparent in any of the present tests.

The apparent diurnal variations in yield (apart from variations in the fresh weight consequent upon variations in the amount of moisture in the herbage) observed in three of the five tests, cannot at present be held to point to any definite conclusions. Such large diurnal variations in the yields of dry matter and of the nitrogenous constituents as those apparently observed, are certainly not to be expected, and the statistical analysis of the data shows them to be below the 20 to 1 level of significance, though this level is closely approached in the test of Oct. 9. At the same time, the association of high yields with the initial (9.30 a.m.) cut and

of low yields with the midday cuts, in these three tests, would not seem to be entirely due to chance; and an analysis of the conditions under which these apparent diurnal yield-variations occurred would seem to suggest a direct and close relation between the yields (including the yields of dry matter and the nitrogenous constituents) at any time of the day and the amount of external water present on the herbage.

Thus, in each of the tests of May 20 and 21 and of Oct. 9, the high yields (whether expressed in terms of fresh herbage, dry matter, or nitrogen) in the initial (9.30 a.m.) cut were associated with the presence of considerable external moisture on the herbage (and in consequence with a high moisture-content of the fresh herbage), whilst the reduced yields in midday were associated with the partial or complete disappearance of this external water (and so with a reduction in the percentage moisture-content of the fresh herbage). Further, the subsequent increases in the yields in the afternoons of May 20 and Oct. 9 were on both days associated with the onset of rain (and so with an increased moisture-content of the fresh herbage due to the presence of external moisture), whilst in the afternoon of May 21, when the weather continued fine, with no change in the moisture-content of the fresh herbage (no external moisture present), there was no change in the yield values. In the test of Oct. 11, when practically no external water was present at any time of the day, no diurnal variation was observed in either the moisture-content of the fresh herbage or the yield-values, though on the other hand, on June 28 a significant reduction in the moisture-content of the fresh herbage, with the disappearance of the dew, was observed during the morning, with no change in the yields of dry matter or of the nitrogenous constituents. It would seem, therefore, apart from the results of the June 28 test, that variations in the amount of external moisture on the herbage during the day influenced in some way the actual yield of herbage (including dry matter and nitrogenous constituents) obtained at different times of the day under the conditions of cutting employed.

Pending further investigations, however, and for the reasons given earlier, it is felt that the reality or otherwise of these apparent diurnal variations in yield must remain an open question.

Whereas the apparent relation, just discussed, would seem to suggest that changes in the percentage of moisture in the fresh herbage during the day were able in some way to influence the actual yield of herbage (whether expressed in terms of fresh herbage, dry matter, or nitrogen) obtained under the cutting conditions employed, definite evidence of the existence of a separate relation between these two values is also afforded by certain of the results from individual plots for those cuts taken when external moisture was present on the herbage in appreciable amount, and more particularly in the tests of May 20 and 21. In these cases, a close direct relation was observed between the moisture-content of the fresh grass *from individual plots* and the *plot* yield, whether expressed in terms of fresh weight, dry matter, or nitrogen. It would, of course, be expected that the density of growth, and, therefore, the amount of grass present per unit area would influence the actual extent to which external water would be held, and it seems probable that this relationship between

percentage moisture-content and plot yield, when external moisture was present in appreciable amount, was due to this cause.

From the results of the tests it would appear that there will not usually be any significant diurnal variation in the nitrogen-content of the dry matter of the herbage, though the apparently significant fall in this value in the middle of the day, in the test of May 21, suggests the need of further study.

Finally, we suggest the need of investigating the yield and composition of cut pasture herbage at different times of the day, under weather conditions differing from those of the present tests, and more particularly under drier and hotter conditions.

Summary

Replicated, small-plot field tests carried out at Jealott's Hill on five days under varying but generally normal weather conditions in May, June, and October 1935, in which pasture herbage at a stage of growth suitable for conservation, was cut at 1½- or 2-hourly intervals throughout the day, to within 1 in. of ground-level, showed that the percentage moisture-content of the cut herbage normally fell significantly during the day, reaching its lowest value between noon and 3 p.m. This reduction was apparently associated almost entirely with the disappearance of external moisture usually present on the herbage early in the day.

Some evidence was obtained of an apparent diurnal variation in the yield of herbage. In three out of four of the tests where external moisture was present on the herbage in appreciable amount at some time of the day, an apparent close, direct relation between variations in the amount of this moisture and variations in the yield of herbage, whether expressed in terms of fresh herbage, dry matter, or the nitrogenous constituents, was observed; thus, high yields were apparently associated with the initial morning cut, and substantially lower yields with the midday cuts, and in the afternoon the yields (including those of dry matter and the nitrogenous constituents) increased again under rainy conditions and remained at their midday level under fine weather conditions. On the other hand, these apparent diurnal yield-variations were not in any instance statistically significant, judged on the probability level of 20 to 1, though sometimes nearly so; their reality therefore needs further investigation. In four out of the five tests no significant diurnal variation in the percentage nitrogen-content of the dry matter of the herbage was observed. In one test, in May, there was an apparently significant fall in this value in the middle of the day.

The application of our results in the conservation of grass, particularly by artificial drying, is discussed, and further investigation is suggested.

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APPENDIX

Yields of Fresh Herbage, Dry Matter, and Nitrogen. gm. per 18 in. square plot (average of 3 replicates)
Average Percentage of Water in Fresh Herbage, and corresponding Water Ratio
Average Percentage of Nitrogen in Dry Matter

Constituent	Time of cutting. Weather and grass conditions*					Standard error	Value of Z	
	9.30 a.m.	11 a.m.	1 p.m.	3 p.m.	5 p.m.		Found	Fisher's Table ($P = 0.05$)
MAY 20								
	Showery	*Showery*	*Dull, but no rain*	*Heavy rain*	*Heavy rain*			
	Grass very wet	*Very wet*	*Wet*	*Very wet*	*Very wet*			
Yield of fresh herbage	340	249	169	253	..†	..	..	..
Yield of dry matter	58·7	46·4	33·3	46·3	..	5·56	0·623	0·780
Yield of nitrogen	1·88	1·29	0·88	1·31	..	0·195	0·748	0·780
Percentage of water in fresh herbage	82·6	81·3	79·9	81·6	81·7	0·569	0·513	0·673
Water ratio	4·75	4·35	3·98	4·44	4·46	..	..	..
Percentage of nitrogen in dry matter	3·16	2·76	2·64	2·81	2·88	0·144	0·307	0·673
MAY 21								
	Fine and sunny all day							
	Grass very wet	*Very wet*	*Almost free of external moisture*		*Dry*			
Yield of fresh herbage	345	307	223	233	225	..	..	..
Yield of dry matter	62·5	57·1	48·2	52·2	51·1	4·55	0·215	0·673
Yield of nitrogen	1·77	1·62	1·20	1·39	1·40	0·122	0·588	0·673
Percentage of water in fresh herbage	81·7	81·4	78·2	77·5	77·3	0·407	1·671	0·673
Water ratio	4·46	4·38	3·59	3·44	3·41	..	..	..
Percentage of nitrogen in dry matter	2·82	2·84	2·50	2·67	2·74	0·064	0·751	0·673

Constituent	Time of cutting. Weather and grass conditions*						Standard error	Value of Z: Found	Value of Z: Fisher's table ($P = 0.05$)
	9.30 a.m.	11 a.m.	12.30 p.m.	2 p.m.	3.30 p.m.	5 p.m.			
JUNE 28									
	Warm and sunny all day								
	Grass wet with dew	*Appreciably drier*	*Almost free of external moisture except for patches at base*						
Yield of fresh herbage	300	268	297	313	269	293	..	..	..
Yield of dry matter	56·2	54·4	62·4	64·9	58·6	62·6	3·26	0·229	0·601
Yield of nitrogen	1·11	1·05	1·15	1·25	1·08	1·22	0·082	Not significant†	..
Percentage of water in fresh herbage	81·3	79·6	78·9	79·3	78·2	78·6	0·505	0·763	0·601
Water ratio	4·35	3·90	3·74	3·83	3·59	3·67	..	..	..
Percentage of nitrogen in dry matter	1·98	1·92	1·84	1·92	1·84	1·95	0·074	Not significant	..
OCTOBER 9									
	Dull and windy				*Drizzle*	*Rain*			
	Grass very wet	*Wet*	*Much drier*	*Dry*	*Wet*	*Very wet*			
Yield of fresh herbage	286	177	147	142	232	235	..	..	..
Yield of dry matter	46·4	33·0	30·4	32·8	43·8	38·8	3·59	0·598	0·601
Yield of nitrogen	1·14	0·83	0·72	0·74	1·01	0·88	0·090	0·588	0·601
Percentage of water in fresh herbage	83·7	81·3	79·2	76·5	81·1	83·5	0·814	1·203	0·601
Water ratio	5·14	4·35	3·81	3·26	4·29	5·06	..	..	..
Percentage of nitrogen in dry matter	2·43	2·51	2·39	2·26	2·34	2·28	0·117	Not significant	..
OCTOBER 11									
	Fine and sunny			*Light shower at 1.45 p.m.*	*Fine and sunny*				
	Slight external moisture in patches at base			*Grass slightly wet*	*Dry*	*Becoming damp with dew*			
Yield of fresh herbage	147	202‡	168	130	141	167	..	..	..
Yield of dry matter	31·7	42·7‡	36·1	31·6	32·5	35·9	2·68	0·458	0·601
Yield of nitrogen	0·79	1·05‡	0·91	0·75	0·78	0·87	0·070	0·456	0·601
Percentage of water in fresh herbage	78·4	78·7	78·2	75·6	76·9	78·4	0·905	0·298	0·601
Water ratio	3·63	3·70	3·59	3·10	3·33	3·63	..	..	..
Percentage of nitrogen in dry matter	2·51	2·45	2·49	2·36	2·41	2·43	0·104	Not significant	..

* Weather conditions during intervals between cuts. Notes on the condition of the grass, indicating the presence or absence of external moisture and its approximate extent.

† Owing to the continued heavy rain it was not possible to obtain accurate yields.

‡ High values due mainly to an abnormally high yield from one of the three replicate plots.

MECHANIZATION IN BRITISH FARMING

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THE term 'mechanization', in connexion with British farming, was first used to describe the specialized cereal farms which came into being about six years ago. These farms flouted tradition first by operating, sometimes in districts wedded to strictly orthodox systems of farming, on a simple rotation of one or two cereal crops followed by a bare fallow; and, secondly, by making such extensive use of tractors, combine-harvesters, and wide cultivating implements that regular labour requirements were reduced to something like one man per 250 acres. As a result, the costs of cereal-growing were reduced to rather less than £5 per acre for a four-quarter crop, and, since wheat, the crop mainly grown, was subsidized, a profit was assured so long as the land could be kept in good heart by mechanical working and chemical fertilizers alone. This was mechanization in its strictest sense, for on these farms labour-saving machines and methods adopted *en bloc* from overseas controlled the whole system: everything else was modified or eliminated to suit the machine's requirements.

Whether it is possible, or even desirable, for this type of farming to be widely practised in Great Britain need not be discussed, since at the moment hardly any farms retain it in its original form. In nearly every case specialist farmers have introduced one or other form of live stock or an alternative field crop just as soon as there has been any prospect of their being able to do so profitably. At the same time, even the most ardent opponents of specialized cereal-growing could not disregard the economies that had been effected, partly by the use of mechanical power, and partly by concentrating on a limited range of products. The result has been the rapid evolution in Great Britain of a system which, since it depends very largely on the use of mechanized power, is still called mechanized farming but which, because it may also involve many changes not directly concerned with machines, might be described more accurately as rationalized farming. Since it has derived partly from an extension of activities by specialist farmers, partly from the adaptation of some of their methods by more orthodox arable farmers, and partly from the invention of new methods applicable to particular circumstances, the ramifications of mechanized farming in its newer sense are very wide. There is, in fact, no such thing in Great Britain as a typical mechanized farm. But certain general features, applicable in a greater or lesser degree to all the farms which have any claim to be regarded as mechanized, can be recognized. Among them are:

1. The replacement of horses by tractors whenever by so doing the output per man can be increased.
2. The elimination as far as possible of unnecessary or unprofitable operations. Two typical examples, one involving machines the other not, are the elimination of stooking and stacking by the use

of the combine-harvester, and the elimination of manure-carting by the use of folding-systems of pig- and poultry-keeping.

3. The modification of farm rotations, not by departing altogether from orthodox methods, but by concentrating on those crops whose production costs can most easily be lowered or on those which will give an immediate cash return. In either case, each product must be prepared to stand on its own legs. An arable crop which requires dung must be prepared to pay all the costs of preparing and hauling it; and if the live stock needs straw the same principle must apply.

The mechanization of mixed farming on these lines was the subject of a Conference at Oxford earlier in the year, and in the published Proceedings [1] are included several accounts of the working of individual farms. It is not proposed here to discuss these or any other particular farm, but only to give a general account of the new methods used in some of the more important farming operations.

Tractors and Power Cultivation

Broadly speaking, the tractors commonly used on mechanized farms in this country fall into three classes: track-laying tractors of from 18 to 25 drawbar horse-power; standard type wheel-tractors generally from 10 to 15 d.b. h.p. but sometimes larger; and general-purpose wheel-tractors in a variety of sizes usually not exceeding 15 d.b. h.p. Practically all the original specialized farms relied for their main source of power on track-laying tractors capable on average land of pulling a four- or five-furrow plough. Track-layers were regarded as essential because of a fear that spring cultivations might be delayed by the land being unfit for wheeled machines early in the year. More recently it has been realized that although wheeled tractors may not be able to work the land as early as horses could, they have little difficulty in making up for lost time once the land is fit. And so, although track-layers are still popular on the original mechanized farms, there is a tendency for newcomers to mechanization to favour wheeled tractors on account of their lower rates of depreciation. The size of the main power-unit has, in most cases, been decided on the one hand by the need for a machine powerful enough to pull a standard combine-harvester at the reduced speed which heavy long-strawed crops require, and on the other hand by the difficulty of providing a sufficient load for a really large machine. In ploughing some of the lighter lands even a 20 h.p. tractor requires seven or eight furrows for a full load, and two ploughs coupled together are occasionally used. But for the most part ploughing is done by single-unit implements of four or five furrows, and tractors of more than 25 h.p. are not at all common.

Lower-powered wheeled tractors are used on nearly every farm for odd jobs: haulage both of seed and fertilizers at sowing-time and of crops at harvest-time; light work such as mowing and harrowing; and in a few cases where ploughing is done in 'lands', for setting out the work. Increasing numbers of these tractors are being fitted with pneumatic tyres to facilitate haulage, particularly where public roads must be traversed—

as is commonly the case on British farms—and to allow higher working-speeds to be used on occasion. General-purpose or row-crop tractors are being used to bring potatoes, sugar-beet, and certain vegetable crops into the range of mechanizable products. British farmers do not like implements built on to or around their tractors, so standard American row-crop equipment is hardly ever seen in this country. As an alternative, various British-made row-crop units are available and can be provided with attachments for carrying out most kinds of row-cultivation. These units have developed from the old steerage horse-hoe and, although directly attached to the tractor, are placed behind it on their own wheels, so that they can be removed or replaced very quickly. They require two men to work them, a tractor-driver and a man steering the hoes or cultivators, and are generally capable of covering a working width of about 9 feet.

Most of the other cultivating implements used do not differ appreciably except in size from those used on ordinary farms. An exception is the disk plough, which was never used with horses in this country, but which is becoming increasingly popular as a tractor-implement. There is some difference of opinion in regard to ordinary disk ploughs, although there is little doubt that they will reproduce on some land the work of digger-breast mould-board ploughs with a considerably reduced cost of maintenance. The so-called one-way or poly-disk ploughs are generally recognized as efficient implements for stubble-breaking, cross-ploughing, particularly in fallow-making, and for seed-bed preparation.

Fuller details of the cultivating methods practised on mechanized farms are given in a bulletin by Newman [2]. As this brief review indicates, however, very little in the way of spectacular equipment is used. Rotary cultivators and similar devices are uncommon and the gyrotiller—a giant machine which might well be taken as a symbol of mechanization—actually plays little part in the system. The machine is too large to be generally used except on contract work; and mechanized farming of the kind under consideration is essentially a matter of farming with one's own equipment.

The Corn Harvest

The working of the specialist cereal farms was based on the use of the combine-harvester; indeed, the successful demonstration of the machine under British conditions in 1928 and 1929 led immediately to the development of these farms. Judged by direct results the combine-harvester has been completely successful in this country. On account of the greater bulk of our crops the cutter-bars of standard American machines had to be reduced in width, generally to 12 ft.: whilst the vagaries of our climate made the provision of grain-drying equipment essential. With these modifications the new method reduced grain-harvesting costs by about £1 per acre by comparison with ordinary methods of working with horse-drawn binders, and, at the same time, greatly reduced the risk of damage by unfavourable weather. In recent years, however, the combine has hardly made as much progress as might have been anticipated, and in 1935—the sixth year of its use on

commercial farms—there were, excluding a few demonstration and contract machines, only 41 actually at work in Great Britain. The work of these machines and the organization of some of the 31 farms employing them have been described by Bridges and Whitby [3].

Where combines are not used harvest-mechanization has consisted only in the use of wide-cut tractor-binders and in a gradual extension of the practice of threshing from the field without intermediate stacking. In the absence of detailed costs of the latter method, it is difficult to judge whether it is appreciably more expensive than 'combining'. In any case the answer will depend on the value placed on the straw which combine-users generally plough in or burn. On one well-known mechanized farm as much straw as possible is being collected behind the combine, and is sold by the cereal department to the live-stock branch —an indoor pig herd—at £1 per ton. Quite apart from whether the straw is worth as much as this to the pigs, a value of £1 per ton would appear to make the overall economy of the combine-harvester rather doubtful. Some farmers consider that combine-harvesting has other disadvantages: the grain must be marketed immediately unless expensive storage accommodation is provided; and weed seeds are broadcast over the stubbles. The first of these, of course, would apply equally well to any method of threshing direct in or from the field. The second may, in the long run, prove serious. On the whole, whilst it is certain that more combines will be used, it is doubtful whether the machine will ever become universal unless the new continental machines, which aim both at threshing the grain and binding the straw, and which are being made on a scale more appropriate to our small fields, are successful. The grain-drier, however, is likely to become a permanent feature of our countryside, for its advantages in our uncertain climate are quite definite.

Haymaking and Grass Conservation

Mechanization of haymaking has consisted simply of the speeding-up of cutting by means of tractor-mowers, and of carrying by means of hay-sweeps, or loaders and mechanically hauled wagons. The ability of the tractor-mower to cut some 25 acres per day—as against 8 or 10 acres with a two-horse machine—allows cutting to be delayed until a spell of fine weather has set in, and so makes haymaking easier from the start. But the greater advantages of mechanization are realized when the hay is made and needs only to be gathered in as quickly as possible. Whatever actual method of collection is used, the tractor saves valuable time because of its greater travelling speed. For sheer speed of working, however, motor sweep-rakes attached to the front of second-hand high-powered cars and used in conjunction with an overshot stacker are superior to anything else. According to an article in an earlier number of this *Journal* [4], three motor-sweeps and a stacker raise the output of a team of workers to something like three times what they could do by hand-forking into horse-drawn wagons. This method cannot be used where it is inconvenient to stack the hay in the field, nor is it so effective where the land is set up in steep 'ridges'.

The article referred to above [4] also describes the working of an American

'pick-up baler'—the equivalent in haymaking of the combine-harvester—which was tried out in this country in 1932 and 1933. The machine worked reasonably well, but on account of its high cost and relative slowness made no appeal to our farmers. There is, on the other hand, an increasing tendency to use motor-sweeps in conjunction with a stationary baler in the field. The hay can be taken at once for storage elsewhere, the cost of subsequent cutting-out is avoided, and there is a possibility that a better product can be made, since it appears that hay can be baled in rather greener condition than that in which it would be safe in a stack. On the whole, mechanized haymaking aims at minimizing weather risks rather than lowering costs. The newest method of all—artificial drying—aims at eliminating the weather altogether. Attempts at drying hay artificially have failed in the past mainly because in a good season drying has been unnecessary, and in a bad one the process has cost more than the value of the final product. Recent work on the feeding-value of dried young grass, however, has put artificial drying in a different perspective. The final product produced by modern drying-plants is not hay but a much more valuable one: dried young grass with all its original properties unimpaired. The process is fully described in both its theoretical and practical aspects in the Conference Proceedings already mentioned. At the moment the plant is expensive, and the process available only to large-scale farmers; but this is likely to be altered in the near future.

Efficient methods of collecting the cut material have already been developed; and the fact that it costs no more to dry good grass than bad has given an added stimulus to grassland cultivation.

Mechanization and Mixed Farming

With a few exceptions, of which the most important is the milking-machine, mechanical appliances cannot be applied directly to reduce the costs of live-stock husbandry. In consequence, mechanization in mixed farming is concerned mainly with so rearranging the system that the economies which the methods already discussed can effect in crop-production are not lost when the crops concerned have to be fed to stock on the farm. This is very largely a matter of transport: either of making transport more efficient or of eliminating it altogether. An extreme example is provided by Mr. Hosier's system of which a full account has been given by Orwin [5]. It is a system of alternate grass and arable husbandry arranged so that hay and straw are used near where they have grown, and all the live stock is folded on, or ranges over, the grassland. There is, thus, no dung-carting, and very little haulage of feeding-stuffs. In this particular case milk is the primary product, and an ingenious portable milking-shed is a feature of the system. Methods, similar in principle, are, however, being more widely used every year with poultry, pigs, and even fattening cattle; but since they all involve out-wintering stock they are necessarily confined to land which will stand treading under wet conditions.

On other types of land mechanized live-stock production depends on making the best use of pneumatic-tyred tractors and trailers, and on adapting yards and buildings to facilitate loading and unloading. The

extent to which mixed farming will be mechanized in the future depends very largely on whether our farms can be reorganized into rather bigger units than are common at present. Both because the size of some of the machines concerned is being reduced and because there is a growing appreciation of the fact that, in general, equipment wears out only in proportion to the amount it is used, prevailing estimates of the limiting acreage which can be economically mechanized are gradually being lowered. The process cannot, however, go on indefinitely, and sooner or later it must appear that farms smaller than, say, 300 acres are definitely uneconomic, at any rate for corn and hay, whether they are to be fed on the farm or not. On the other hand, it is doubtful whether mechanization need involve very large farms for, on the practical evidence now available, it would not appear that there is much to be gained by the mere multiplication of working-units.

Apart from such questions of the size of unit, there would appear to be no limits to the spread of mechanization. It is true that few of the farms so far mechanized are situated on the heavier soils, but this is due mainly to the fact that in Great Britain large farms tend to be associated with light land. Mechanization of heavier land may mean using more track-laying tractors and will certainly involve higher working-costs, but there should be heavier crops by way of compensation. It is also true that the labour requirements of some crops cannot be reduced very much, even by mechanization. But these crops are the exception rather than the rule and various ways of doing without them are being worked out. Perhaps the most far-reaching development of all, and the one which will influence the spread of mechanization more than anything else, is artificial grass-drying. The greater part of the country is devoted to grassland and at present depends for its concentrated winter foodstuffs on sources outside agriculture. If these concentrates can be provided on the farm in the form of dried grass, enormous possibilities are opened up, and a more general system of alternate husbandry is likely to result.

Short- or medium-term leys devoted partly to grazing and partly to the making of dried grass will increase the productivity of what is now permanent grassland, enable fertility and humus-content to be cheaply maintained, and, enable the benefits of mechanization to be fully realized.

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